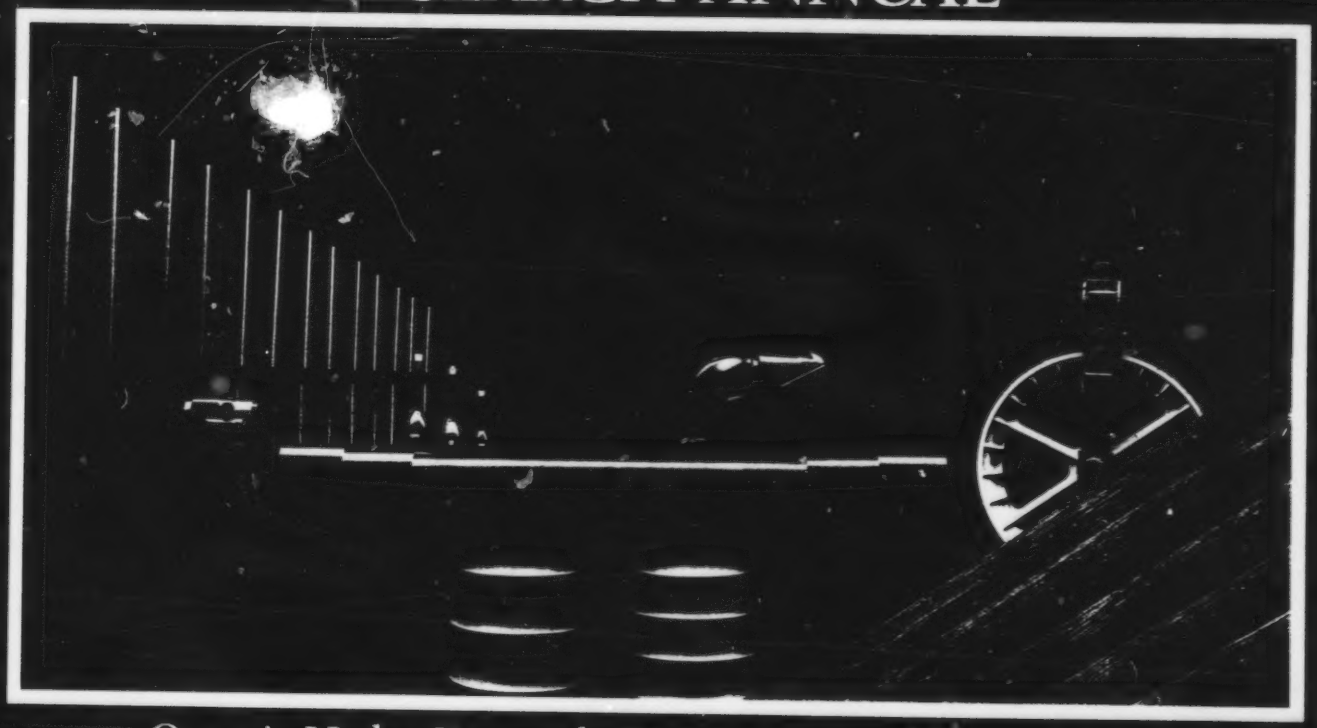
Ontario Hydro

RESEARCH ANNUAL



Ontario Hydro Research Division Annual Report 1988

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The Research Division's Commitment

Customers: Meeting changing needs
Demand Management: Using energy efficiently
Supply Management: Examining every option
Environment: Minimizing ecological costs
Corporate Management: Meeting employee needs

VICE-PRESIDENT'S MESSAGE

Lorne McConnell and Bruce Semper, Vice-President of Operations at Davidson Instrument Panel (a subsidiary of Textron Inc.), discuss the use of microwave heating to help solve a hazardous waste problem.

Ontario Hydro's highest priority has always been to provide its customers with products and services synonymous with the highest possible value. To help meet this goal, in May of 1988, a new Corporate Strategy was approved by Hydro's Board of Directors. The new strategy will shape Hydro's operating environment for the foreseeable future. The critical challenge the Corporation faces is to implement this strategy without losing sight of society's evolving attitudes and expectations. In a context hallmarked by change, Ontario Hydro must commit itself to innovation, continuing, at the same time, to build on its traditional strength as a supplier of efficient, safe, and relatively inexpensive electrical power.

The renewed Corporate emphasis on innovation and efficiency and its commitment to dealing with environmental issues have served only to reinforce directions already being pursued by the Research Division. Promoting customer awareness of efficient use of energy and responding quickly to customer requests for advice and assistance are important parts of the Research Division's mandate. Equally important is the Division's role in helping the Corporation ensure the Province of Ontario that the Corporation's facilities and activities are environmentally sound.

Considered as a pioneer in the field of environmental research, the Research Division continues a comprehensive acid rain research program while, more recently, it has focused close attention on studies related to the so-called "greenhouse" effect. More so than any other issue, the implications of this effect are considered to have the ability to impact on the environment on a global scale.

The Research Division's awareness of emerging environmental issues has caused no decline in the pursuit of technologies allowing the provision of the greatest net benefit to Ontario Hydro's industrial customers. By continuing to do high quality research and development, by helping customers make the best use of electrical power, and by disseminating knowledge enabling Ontario's manufacturers to improve the quality of their products, the Research Division has helped forge and assure Ontario Hydro's role as a leader in the energy field.

L. G. McConnell
Vice-President
Power System Program

DIRECTOR'S MESSAGE

Don Mills and Lew Hutchinson, President and CEO of LASCO, discuss electric arc furnace technology, a major interest of Ontario Hydro for which a research facility has been developed at Lakeview.

The mission of the Research Division is to provide Ontario Hydro with the scientific knowledge and technology needed to solve the problems of today and to anticipate those of tomorrow. As Hydro is faced by an ever widening range of technologies, both traditional and new, decision making that remains viable and applicable in the future becomes increasingly difficult. It is fortunate then that research by its nature is open ended: it does not neglect the proven nor does it falter its ongoing search for the possible. The Research Division has a very real role to play in helping Ontario Hydro implement its new Strategy intended as a means of dealing with economic and technological change.

Many of the initiatives undertaken at the Research Division in support of Corporate Strategy are already in place. The need to promote customer awareness of efficient use of electricity and to respond quickly to customer requests for advice and assistance has been a high priority for some considerable time. One benefactor is Ontario industry, and product and process evaluations are conducted in close cooperation with industrial customers. Another is the residential sector. Residential energy efficiency potential is being aggressively explored. The ultimate result will be an increase in the health, wealth, and comfort of Ontario Hydro's residential customers as well as an increase in the Corporation's control over demands made on the bulk electricity system and local distribution networks.

Equally important to reducing power demand is sustaining a reliable supply management program. One important aspect of this program is the need to focus attention on existing generation, transmission, and distribution facilities. To meet one aspect of this need, the Research Division has committed a major component of its resources to the Corporation's extensive life assessment program that will assure the continued safe, reliable, and economic operation of existing plant, be it thermal, hydraulic, or nuclear.

In its pursuit of the scientific knowledge and technology needed to meet the challenges that the Corporation faces as it prepares for the next century, the Research Division is always aware that the environment cannot be traded off for the sake of progress: it commits to design and to carry out its research and development plans in a way that ensures that environmental concerns are addressed. Guided by Corporate Strategy, effective planning within the Division will continue to build in the flexibility needed to meet the needs of a variety of circumstance. Customer satisfaction, reliable supply, and reasonable cost will be the criteria for making decisions that are environmentally sound, technically reliable, and financially feasible.

D. Mills
Director
Research Division

Ontario's citizens want more than efficient, safe, and reliable electrical power supplied at reasonable cost. A more sophisticated public increasingly views the provision of electrical power as a service like any other to be judged on the basis of value added, not on the basis of price alone. A major concern is the environment, which cannot be seen as something to be traded off for the sake of progress. As Ontario Hydro's Chairman and President, Robert Franklin, puts it, the condition of the "environment is a measure of society's standard of living, rather than a good to be bartered or compromised for technological achievement".

It was against this backdrop of public concern, coupled with an appreciation of how macroeconomic trends and new technologies are revolutionizing the economy and the industrial structure, that Ontario Hydro revised its Corporate Strategy. Reflecting changes in customer expectations and the society it serves, the Strategy will guide the Corporation in its business activities through to the end of the century.

The Strategy focuses on five key areas, which are customers, demand management, supply management, the environment, and corporate management. The Research Division is strongly committed to this Strategy and what follows is an account of some initiatives undertaken in support of it.

For Ontario Hydro, the provision of the greatest net benefit to its customers, both collectively and individually, and the pursuit of economic demand management options consistent with Government policy are highly interrelated. And, in 1984, when forecasts indicated a possible shortage of generating capacity in the 1990s, planning to meet increased needs resumed. Since then, considerable effort has been put into developing new approaches to help customers reduce their electricity costs without harm to the environment. The Process Metallurgy Project, a new Research and Development (R & D) activity conceived within the Divisional Projects Department and nurtured by the Metallurgical Department, is one which, while meeting the needs of Ontario Hydro's customers, impacts significantly on both demand management and on environmental concerns.

The Process Metallurgy Project signals a radical departure from the type of work that has historically been undertaken by the Metallurgical Research Department. Rather than being concerned only with the enhancement of materials, components, and processes used for the generation of electricity, the project is aimed at improving the efficiency of energy utilization while assisting in the development of new production technologies. The objective is to allow Ontario's metal producers to maintain a competitive edge.

An electric arc furnace was established to serve as an R & D facility in support of Ontario's metal smelters and melters. Built into the design of the facility is a great deal of flexibility intended to meet the needs of the diverse applications of electric furnaces in the many different segments of the metallurgical industry.

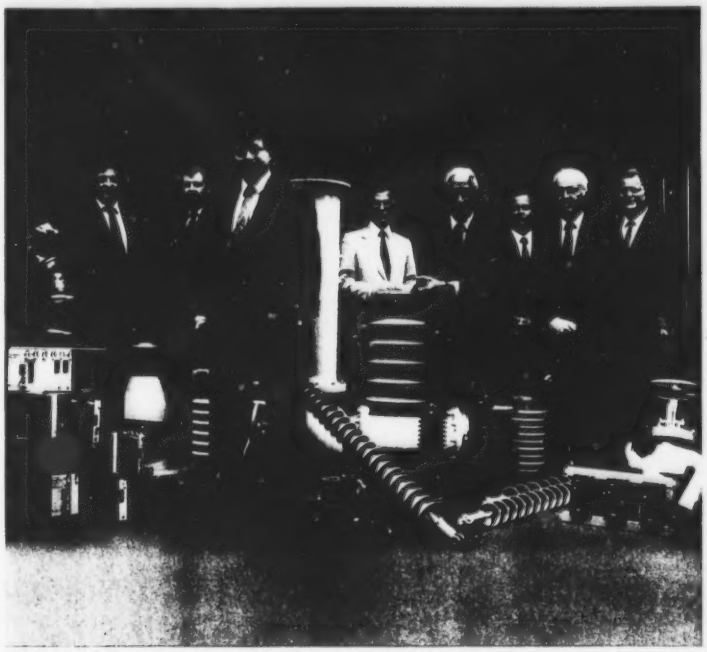
The first project to use this facility is one being undertaken in cooperation with Falconbridge Ltd., a company required by law to bring its sulphur dioxide emissions in line with the requirements of the Provincial Government. Several approaches were under study at Falconbridge. However, what appeared to be the best approach to the problem was found to increase energy consumption. As a response, the Ontario Hydro furnace will be used to examine other ways of dealing with the problem. The process finally selected must help minimize operating costs, thereby allowing Falconbridge to maintain its competitive edge.

The renewed Corporate emphasis on efficiency and conservation has reinforced an already established direction of the Research Division. The Utilization Section of the Electrical Research Department is actively playing the role of facilitator, consultant, researcher, and educator in the development of a number of new electrotechnologies.

Using waste heat from one process as input to another is an efficient and cost effective use of resources. Heat pump technology can be utilized to recover heat from air or water flows. To further enhance efficiency, off-peak thermal storage can be implemented to complement the job. Following the successful demonstration of this type of technology in the restaurant industry, a new project at Ontario Hydro's Orangeville Conference and Development Centre is well underway. Waste heat from the dryer exhaust of the Centre will be used to heat wash water. A concomitant benefit is an improved working environment achieved through space cooling and dehumidification. Power demand reduction and energy savings of 40 to 50 percent are anticipated.

In the Corporate Strategy document, the need to promote customer awareness of efficient use of electricity and to respond quickly to their requests for advice and assistance is stressed. The Research Division continues to emphasize this important strategic thrust; and tests, evaluations, and demonstrations have been conducted for over 60 Ontario companies this year. Evaluations are conducted in close

cooperation with industrial customers, and currently, applications ranging from welding of jewellery with lasers to the treating of waste materials with microwaves have been implemented. All applications have one thing in common: they are intended to achieve the manufacturer's goal of lower production costs and Hydro's goal of reducing demand. Examples of the implementation of such technologies include the successful application of heat pump technology that significantly improved the quality of one food processor's product and that, at the same time, reduced his electricity bill by $64 000 per year; microwave technology that allowed an automotive parts producer to deal with waste materials, thereby reducing both his space requirements and his labour costs; and the installation of a dehumidifier that allowed a ceramics company to expand because of increased quality and productivity.



The eight departments of the Research Division are here represented by their managers. From left to right: T.W. Klym (Civil Research); D.J. Dodd (Chemical Research); N. Anyas-Weiss (Divisional Projects); A.H. Chung (Operations Research); G.J. Clarke (Mechanical Research); J.B. Brown (Divisional Services); A.F. Baljet (Electrical Research); J. Brown (Metallurgical Research).

Work on power demand reduction is not confined to the industrial sector. Residential energy efficiency potential is being explored. There are 370 000 electrically heated homes in Ontario, representing a winter peak demand of almost 4 000 megawatts. The challenge provided by a cold climate is to increase energy savings while decreasing indoor air pollutant concentrations. A survey of 1 000 electrically heated homes is underway to determine the potential for demand reduction and energy savings by using thermal envelope upgrading, energy efficient appliances, and advanced window technologies. Even a modest penetration of such technologies into the existing market could provide more strategic conservation than any other single option. The ultimate result will be an increase in the health, wealth, and comfort of Ontario Hydro's residential customers, as well as more control over the demands made on the bulk electricity system and local distribution networks.

Although demand management is the option of choice in Hydro's efforts to meet customer needs in a responsive way, Corporate Strategy pays considerable attention to the necessity of rehabilitating aging facilities in an orderly and cost effective manner. The Research Division recognizes existing facilities as the most important category of generating plant over the next 20 years and also that rehabilitation of old plant is the more economic alternative to plant shut down.

Experience teaches that the operation of a thermal plant beyond its design life can result in reduced reliability attributable to sudden failure of critical components. But experience also shows that a large fraction of problems arises from a small fraction of components. Ontario Hydro is thus proceeding with a major program of life assessment.

The Research Division believes that the solution to the problem of plant aging is the process of "fingerprinting". In this life assessment process, key components of plant are examined for signs of degradation so that continued operation may be assured or, alternatively, needed replacements may be properly planned.

Some years ago, the Research Division initiated a program to upgrade the flexibility and responsiveness of its metallurgical evaluation capability, and this is of great value in the life assessment process. Traditionally, this type of evaluation was destructive in nature, requiring the removal of each component for laboratory testing, microscopic examination, and any other required testing. Now, new capabilities developed at the Research Division allow the preparation of high-resolution plastic replicas of metallurgical structures.

A key advantage of the nondestructive technique is that it creates a permanent record of a microstructure, which can then be used for comparison when specific areas of concern need to be examined at future times. This new capability can be used in both the laboratory and the field setting, the end result being more reliable plant because of more efficient tracking and assessment of component integrity. The performance of these life assessments alongside the Division's long-term R & D program allows enhanced utilization of resources leading to the increased precision with which repair and replacement decisions can be made.

Like other types of power plants, nuclear stations are susceptible to aging. And because nuclear generation represents the cleanest and, after hydraulic, the second most economic energy source in Ontario Hydro's bulk electricity system, nuclear plant component aging is drawing a great deal of attention. After Darlington is fully in service, nuclear generation will account for about 60 percent of Ontario Hydro's total energy production. Therefore the importance of securing the high performance and safe operation of Ontario Hydro's nuclear stations cannot be emphasized enough.

Within Ontario Hydro, research efforts directed toward ensuring the optimal performance of its nuclear plant are covered by the two components of the Nuclear Plant Life

Assurance (NPLA) Program. One component of the program is committed to assure the life of Ontario Hydro's nuclear plants during the normal service life of 40 years by maintaining their long-term reliability, availability, and safety. The other component concerns life extension, which preserves the option of extending the life of Ontario Hydro's nuclear plant beyond a normal service life of 40 years. These objectives are consistent with the demands of Corporate Strategy, which emphasize that the reliability of Ontario Hydro's existing nuclear facilities will continue to be important in meeting Ontario's electricity requirements beyond the year 2000. The emphasis of the program at present is on life assurance.

A nuclear plant has thousands of components, all of which age with time. The first step in the proposed NPLA methodology is to divide plant components into two categories, critical and noncritical. Noncritical components are those that can be easily and economically replaced and critical ones those that are neither easily nor economically replaced, the failure of which would impact negatively on the safety, reliability, and life expectancy of a plant. Based on specific selection criteria, the list of critical components is prepared and includes components such as fuel channels; steam generators; the calandria vessel, its supports and cooling system; primary and secondary heat transport piping; vacuum building; and cables.

The second phase of the program, "scoping", serves to identify what needs to be done. For each critical component new initiatives required to achieve the following are identified:

1. An understanding of the aging mechanism through an analysis of operating history;
2. A condition assessment;
3. An early detection and prediction of age-related degradation;
4. A slowing down of age-related degradation through utilization of proper operating and maintenance procedures; and finally
5. Restoration of lost performance through repair, refurbishment, and replacement.

The NPLA program is strategically important to Ontario Hydro's future, and although much progress has been made toward understanding and managing the consequences of aging, not all aging-related issues are fully understood. Work still needs to be done in areas such as irradiation embrittlement of metallic components, assessment of concrete aging, and development and validation of "remaining life" prediction models through laboratory and field testing. The Division's R & D effort carried out in support of NPLA is therefore essential. Results of work done by other utilities are undeniably of benefit to Ontario Hydro's program, but, because the CANDU system is unlike any other, Ontario Hydro, along with Atomic Energy of Canada Limited (AECL), must stand virtually alone.

In terms of new supply options, Corporate Strategy demands that preference be given to developing non-utility and any remaining hydraulic sources. In addition to pursuing the development of new economically and environmentally viable locations, Hydro's commitment to existing hydraulic facilities is reflected in the establishment of the Corporate Dam Safety Program. The Research Division, as part of the interdisciplinary dam safety team, has made a major contribution in its provision of state-of-the art technical support.

In the decades since Ontario Hydro's water-retaining structures were built, evaluative techniques and equipment have changed. Modern techniques are used to obtain appropriate strength parameters and to probe an existing dam for weaknesses. Advanced in situ testing devices, such as the dilatometer and the piezocone for use in earth dams and the Soniscope for use in concrete dams, can provide detailed information about a dam.

Advanced drilling techniques, automated data acquisition systems, and remote data transmission contribute significantly to the assessment of dam performance. These new developments are vital in providing the information necessary in the planning required to keep hydraulic stations operating safely and reliably. Maintenance and repair needs are also being served by the development of robots that can be used to maintain vital pressure relief systems in previously inaccessible dams.

Ontario Hydro, accepting that no form of energy is environmentally benign, commits to design and execute its development plans in a way that ensures the continued vitality of the ecosystem. Over the years, environmental concerns have grown in complexity, and no longer can an individual agency proceed as if it alone were involved in a search for information. Recognizing the efficacy of sharing expertise, the Division has participated in collaborative environmental research involving networks of industrial, government, and university agencies for over ten years.

The Research Division continues to investigate a number of options for controlling acid-gas emissions, and an acid rain research program involving dry deposition measurements and cloud modelling continues.

Power plants emit nitrogen oxides (NO_x), which are photo-oxidants. Thus, Ontario Hydro is anxious to define the role of NO_x in the formation and behaviour of photo-oxidants, some of which may play a key role in reactions that lead to the formation of acid rain. The work of the Division is currently focused on making measurements of natural NO_x emissions; analyzing air samples for volatile organic compounds; measuring the size distribution and trace element content of atmospheric aerosols; and measuring nitrogen dioxide dry deposition fluxes. Through direct data analysis and the use of mathematical models based on these measurements and the vast amount of data collected by other participants in the study, ozone concentrations in power plant plumes and in air masses that originate in different areas can be determined.

More so than any other environmental issue, the so-called "greenhouse" effect has the potential to impact on the environment on a global scale. Fossil-fuelled power stations emit two "greenhouse" gases, carbon dioxide and nitrous oxide. The emission of these gases is being monitored. Preliminary results indicate that nitrous oxide concentrations are much lower than the literature suggests.

Another "greenhouse" gas, methane, is increasing its concentration in the atmosphere at the unprecedented rate of one percent per year. The reasons why are not clear, but the Division is involved in a recently initiated Canadian Institute for Research in Atmospheric Chemistry (CIRAC) study that aims to determine the role of the vast Northern Wetlands of

Canada, which are suspected of being a significant source.

Also of great importance is Ontario Hydro's nuclear waste management program. In 1978, the Corporation entered into a technical assistance program with AECL. Since that time, Design and Development — Generation, Nuclear Generation, and Research Divisions have been collaborating in a work program that has developed significant capabilities in areas of nuclear waste management. As a result of this extensive involvement in the Corporate Program, the Division has developed initiatives in nuclear waste storage, transport, and disposal.

Development of methods of high-level waste transport and extended storage is underway. Road, rail, and barge modes of transport are being evaluated, and a special cask is being developed intended for storage, transport, and disposal of nuclear waste. The objective is to create a container able to withstand shock, vibration, and heat. Studies of dry vault design and determination of the temperature limits at which CANDU fuel bundles can be held under dry storage conditions without loss of integrity are in progress. The focus of this latter endeavour is to provide the data needed to determine suitable disposal sites in geological repositories.

Another major initiative arises from the decommissioning of the Nuclear Project Demonstration (NPD) generating station. The station makes available a major source of concrete that has been subjected to varied thermal and irradiation fields during the normal operation period of the plant. Concrete cores have been retrieved from numerous locations, and now, the effect of radiation as well as high thermal fields on the performance of concrete containment structures can be assessed. This work is highly relevant to the evaluation of cement-based materials as engineered barriers for controlling the leakage of radionuclides.

The Strategy document points out that the broad trends toward flexibility and innovation must spill over into the management of the Corporation itself. The strategic emphasis is on providing opportunities and challenges to meet employee needs and on being at the leading edge of research and development of selected technologies beneficial to Ontario Hydro's operations. Two examples serve well to illustrate the Research Division's commitment, both to its employees and to the more global needs of the Corporation. These are the dual ladder career system and the Integrated Computing Environment (ICE).

People are Ontario Hydro's most valuable resource, and for an employee to feel challenged and appreciated, it is often necessary to create a working environment that meets individual needs. In 1986, with these needs in mind, the Division initiated a technical ladder system. The system is flexible, recognizing those Research Division staff who have consistently made outstanding contributions in the technical sphere. On the one hand, Research Division personnel have been able to make their way, traditionally, by promotion up the managerial rungs of unit head, section head, department manager, and director. On the other, nontraditionally, staff now may climb the technical ladder, starting with an entry level position and progressing through more senior levels to the positions of Senior Research Scientist or Engineer and Principal Engineer or Scientist. The latter two positions are equivalent to the section head and manager positions both in status and remuneration.

In a world hallmarked by change, the technical ladder serves the strategic needs of the Corporation especially well. The advent of the CANDU reactor brought with it a whole set of new research questions and a much greater public awareness of environmental issues. Additionally, the amount of relevant research being done elsewhere is increasing dramatically, both nationally and internationally. The strong scientific reputation of employees on the technical ladder allows broad access to new information generated by peers in other research facilities. An additional benefit of the technical ladder is that the senior ranks on the technical ladder have access to, and can influence, the same decision-making bodies as their counterparts on the managerial ladder. The result is enhanced communication that makes it possible for the Research Division to exert a great deal of influence both inside the Corporation and in the scientific community at large.

Enhanced communication was also at the heart of the proposal for the implementation of ICE, a project designed to link researchers by linking computers and other electronic equipment throughout the Division and beyond. Like other Divisions faced with the problem of limited financial resources and the need to make sizable investments in computing resources, the Research Division had to assess how best to take advantage of emerging technology to enhance the capabilities of researchers and at the same time to facilitate the overall administrative effectiveness of the Division. Because controlling costs, managing change, making the most effective use of Corporate resources, and taking advantage of new opportunities faster and more effectively all require the optimal handling of information, a project like ICE seemed both timely and relevant.

Essentially, ICE will provide a data communication system similar to those already implemented in other parts of the Corporation. The benefits of such systems are enormous. The project is cost effective: it allows the sharing of expensive hardware and software, which in turn can be shared by many users. The project impacts on the Corporation's business needs: by implementing a far-reaching and compatible network, a business culture can be unified while, at the same time, its complexity can be reduced. ICE will improve the quality of the working life of the Division's employees: the system will aid in the organization and handling of a steadily increasing amount of data, thereby reducing the work load during the yearly planning cycle. ICE allows wider access to the Corporation at large: the delivery of critical data and expertise to and from the Research Division will be vastly improved, thereby benefitting situations of Corporate importance. ICE will allow the Division the opportunity to participate in, and exchange information with, the research community at large: it allows global access to information about current developments in high-interest areas.

The Division's vital role in helping Ontario Hydro effectively manage change in a future that remains uncertain will continue. Guided by the Strategy document, effective planning within the Division will serve to build in the flexibility needed to meet the needs of a variety of circumstances. The principles of customer satisfaction, reliable supply, and low customer cost will be emphasized. In a time frame that is rapidly shrinking, the choices resulting from R & D will have to be environmentally sound, technically reliable, and financially feasible.

CHEMICAL RESEARCH:

The Chemical Research Department is a technical resource that provides support to the Corporation in the areas of process and materials chemistry, chemical analysis, biology, and environmental science. A staff of about 140 chemists, chemical engineers, biologists, and highly skilled technicians work on a research and development program involving scientific research, technical investigation, and problem solving. Comprehensive analytical and testing services are also provided by the Department.

The research capabilities of the Department were enhanced in 1988 by the acquisition of thermographic and x-ray equipment and associated image enhancement apparatus for the development of expertise in the nondestructive evaluation of non-metallic materials. Analytical capability was increased with the addition of an inductively coupled plasma (ICP) arc spectrophotometer and new mass spectrometer equipment.

Almost one-third of the Department's resources are invested in support of the Corporation's nuclear commitment. This work is wide in scope, ranging from research dealing with nuclear waste management options to modelling the potential spread of contaminants after a simulated loss of coolant accident. A significant effort in support of nuclear generation deals with maintaining steam generator tube integrity.

Degradation of steam generator tubes, which may result in leaks of primary coolant, is a major concern in the operation of nuclear plants. Although Ontario Hydro's CANDU reactors have been world leaders in steam generator integrity, a long-term research program is being carried out to anticipate problems that may occur and to develop remedial measures to avoid or minimize their consequences. Emphasis in 1988 was on the introduction of field studies of the condensate, feedwater, and steam generator water chemistry. The major objective of the chemistry control program is to minimize the rate of ingress of impurities into the steam generators. Transport studies to determine the sources of corrosion products in the secondary circuit during steady operation and during system transients, such as start-up, shut-down, and load-following, have been done.

At Pickering NGS, sampling has been started to determine morpholine levels in the various units and to monitor the concentrations and distributions of its decomposition products. Additionally, the impurities released to the bulk water during unit shut-down have been studied. The result is a better understanding of the chemistry in the crevice region during operation. This shift in emphasis from the laboratory to the field should result in immediate benefit to the stations in that secondary system chemistry will be optimized.

Also at Pickering, during the major retubing operations that started in 1985, work in Units 1 and 2 was impeded by unexpected contamination from carbon-14 in the form of an easily dispersed fine black dust. Research studies showed this to be a carbon-nitrogen polymer. Further research established that oxidation of the carbon-14 could reduce possible contamination during the retubing of Units 3 and 4. Subse-

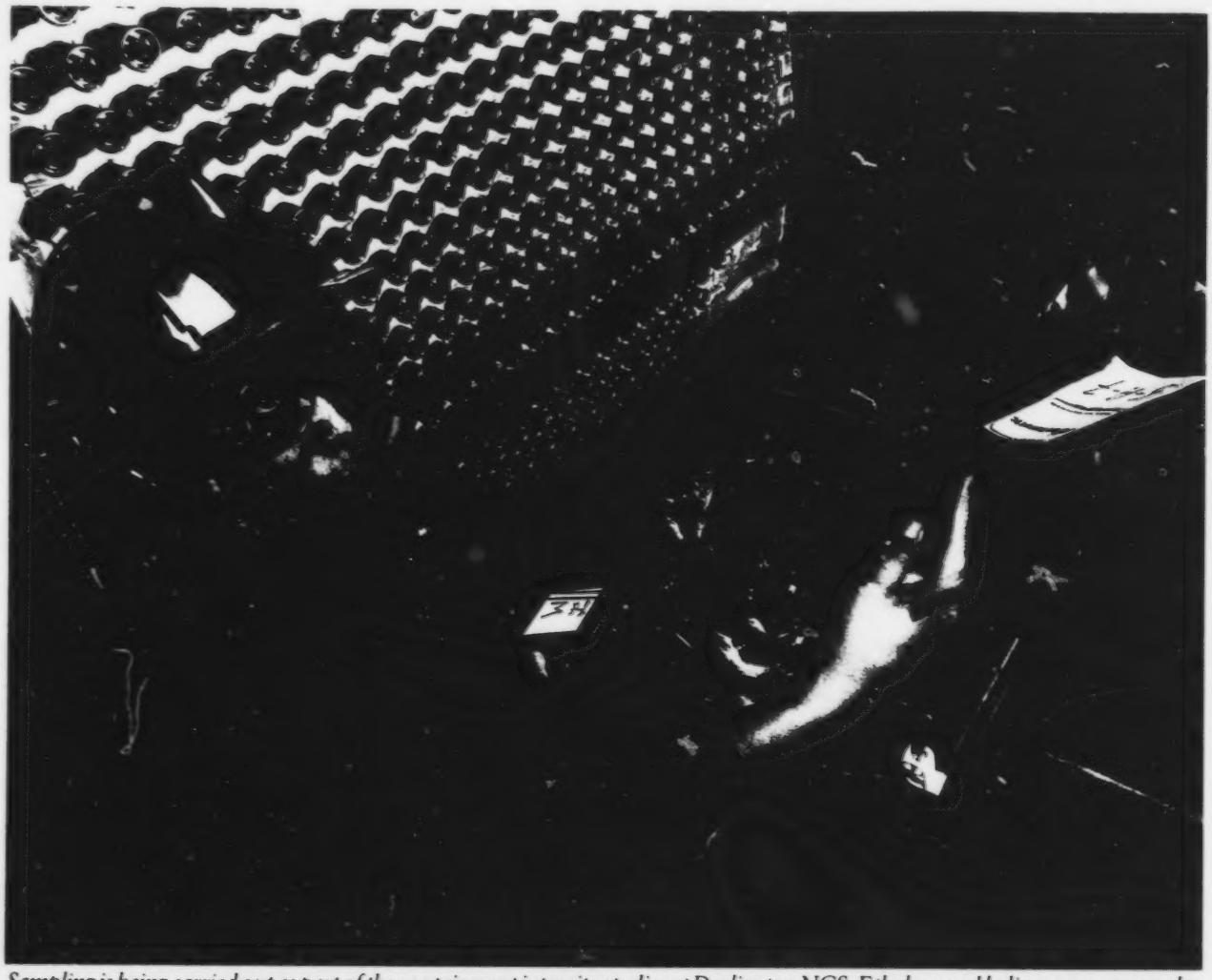
quent trials of oxygen introduction into Unit 4 showed that oxidation rates were enhanced by radiolysis; however, complete system decontamination could take considerable time. Therefore on-power oxidation will be combined with a continuous on-line $^{14}CO_2$ capture system developed by the Chemical Research Department and modified for installation on the Units 3 and 4 annulus gas systems. This removal system will be installed on Pickering Unit 3 before the end of 1988, and long-term oxygen-injection tests with $^{14}CO_2$ monitoring will be undertaken.

The reactor waste management research program undertook characterization of the different waste streams in terms of their chemical and physical composition, activity level, and radionuclide inventory. Knowledge of these waste characteristics is of use to both Design and Operations Divisions. It allows the determination of processing equipment and storage structure requirements and the establishment of the hazard levels of various wastes and the time it takes for them to decay to a non-active status. Additionally, the knowledge allows the determination of the radioactive inventory in storage and the determination of any special disposal precautions that might be required.

Techniques to immobilize and package tritiated wastes for storage and disposal were studied. The wastes that could come from the Darlington Tritium Removal Facility include waste water, oil, and metallic components. Once conditioned by immobilization, the amount of tritium released daily by leaching should be less than 0.001 percent of the initial amount, and the waste package should retain its integrity for 150 years. The research showed that immobilization alone could not retain the tritium adequately, but that the use of 1-cm thick high-density polyethylene containers gave more than adequate retention of tritium and, being corrosion resistant, should provide the desired containment life.

Research studies in the Environmental Program area range from monitoring the effects of Ontario Hydro's operations on ecosystems and assessing the impact of environmental changes on its activities, through meeting new regulations for air and water quality, to developing means of controlling environmental emissions.

To improve the ongoing aquatic surveys at generating facilities, more efficient sampling techniques are being developed. Emphasis is being placed on non-consumptive and remote sampling systems. Options such as radiotelemetry and acoustic sampling are being actively pursued and are expected to figure prominently in studies of fish populations and their movements. Enhancements to existing sonar systems coupled with the application of artificial intelligence concepts have provided encouraging laboratory results. In the future, the ability to distinguish fish from debris by means of sonar techniques, and even to differentiate between species of fish, appears promising. If successful, the expected application of these techniques will make future surveys more effective, environmentally more acceptable, and less costly.



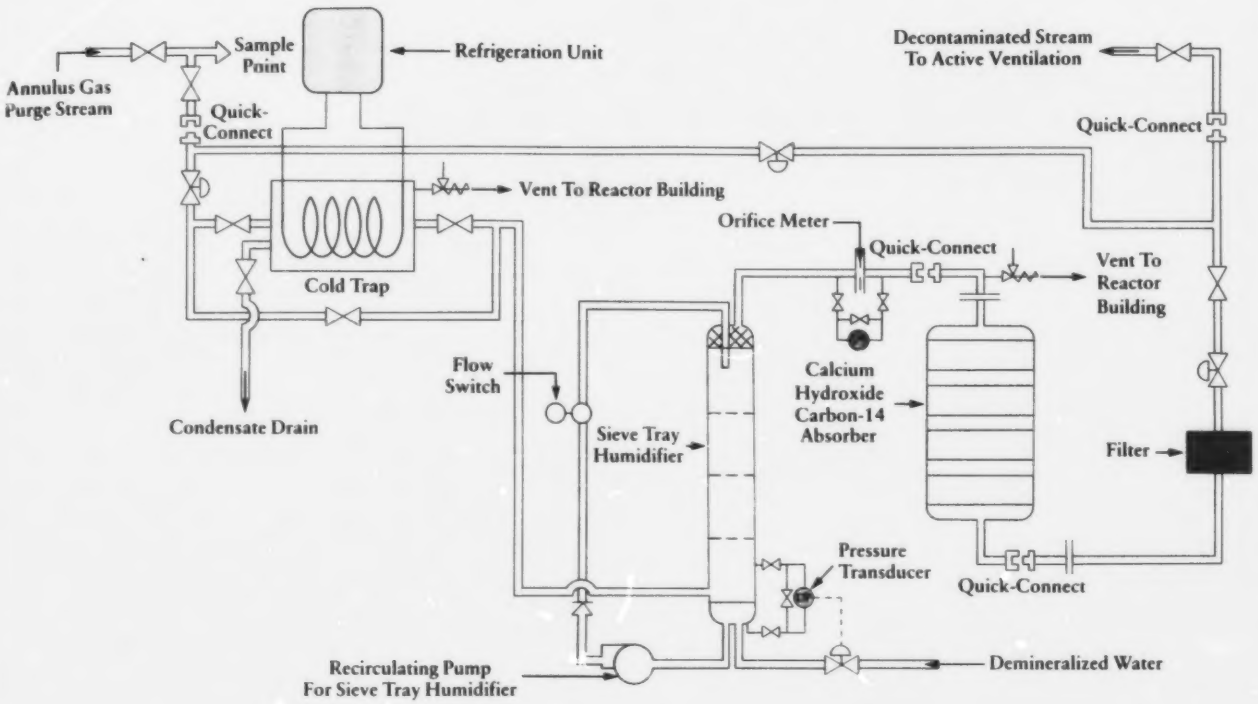
Sampling is being carried out as part of the containment integrity studies at Darlington NGS. Ethylene and helium gases are used to simulate hydrogen gas, thereby giving insight into accident conditions.

During 1988, work in the environmental emissions area concentrated on the reduction of acid-gas precursors. A more extensive account of some of the Department's activities in the environmental area is to be found in the earlier article concerning the Division's contribution to Corporate Strategy.

A program to develop the furnace limestone injection process for reduction of SO_2 emissions from coal fired plants yielded results that could lead to a low-cost process for control of NO_x emissions. In the conventional limestone injection process, it is known that wetting the material downstream of the furnace improves both the efficiency of SO_2 removal and the capture of waste in the electrostatic precipitators. Now, studies of the injection of limestone directly into the furnace in the form of a slurry, which contains a special reducing agent that reacts with NO to produce N_2, show not only up to 70 percent SO_2 capture, but also up to a 90 percent reduction of NO_x emissions. If further pilot-scale and full-scale tests are equally successful, this process could provide a high-efficiency NO_x-control option many times less expensive than currently available technologies.

The reliability of Ontario Hydro's 500-kV transmission system under icing conditions is of considerable concern. Over the last few years, a number of flashovers have occurred, the most serious in March 1986, when the system was shut down during conditions of fog at sub-zero temperatures and during rising temperatures. The mechanism of ice formation under these conditions was investigated in the laboratory at the University of Quebec. A parallel study of the environmental conditions associated with flashover events was carried out in the Chemical Research Department.

The University of Quebec study demonstrated that the increased water conductivity on the surface of icicles and in melt water decreased as melting progressed. The Chemical Department's related environmental study involved the sampling of a number of fogs and the subsequent determination of their chemical composition and conductivity. Frequently, very high conductivities were found. These data suggest that fog may be an effective medium for icing, wetting, and contaminating insulators. The slow melting and thawing of ice, which is produced by water deposited by fog, generates a highly conductive liquid film on the surface of insulators. Further study of these processes will allow the development



Annulus Gas Carbon-14 Removal System Using A Multi-Layer Calcium Hydroxide Absorber

of engineering or operational solutions to the problem.

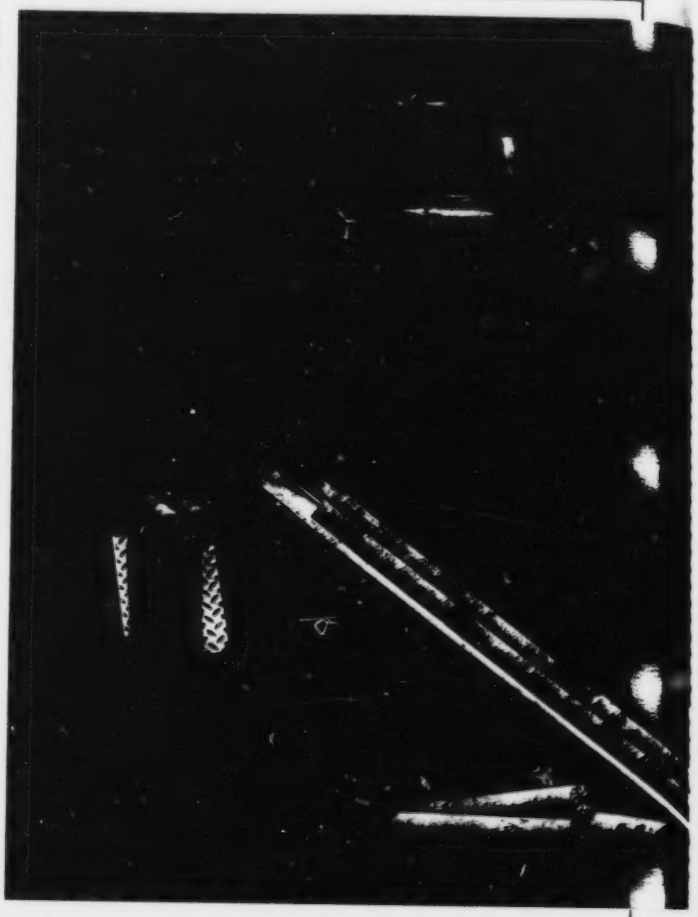
The Chemical Department supports the Corporation's commitment to more efficient use of electricity and the byproducts of its production. To better utilize the inventory of heavy water, its potential non-nuclear use in the manufacture of deuterated materials is being investigated. This research has demonstrated that the substitution of deuterium for hydrogen can improve the oxidation resistance of many oils, greases, and polymers. Evaluation of several deuterated materials has shown that, with this substitution, the service lifetime of polymers can be increased by a factor of three and that of oils by over one hundred times. These improvements in performance can be obtained with any material that degrades by the oxidative breaking of carbon-hydrogen bonds, thus opening up many potential applications for heavy water use.

In support of the commitment to better utilize the byproducts of electricity production, research was undertaken to assess the feasibility of developing a commercially viable Malaysian prawn aquaculture scheme. This particular species of prawn was chosen because of its marketability, rapid growth rate, its large size, and its requirement for warm (27° to 30°C) water. Early stages of this research dealt with the improvement of food and space utilization. During the past year emphasis was placed on population characteristics to ensure uniformity of size.

In 1988, the results of the prawn research were applied in a small greenhouse demonstration with impressive results. The system that was tested yielded production rates equivalent to almost eight metric tons per hectare per year, which is about eight times the global average. In addition the prawns developed to a marketable size in six months, half the commercial rate. The average prawn was 23 grams as compared with shrimp, which are typically harvested at 17 grams. Ninety-five percent of the animals were over 15 grams. Continuing research may improve on these results. Currently a financial study is being carried out, and if warranted, the feasibility of a pilot-scale plant will be considered.

Research aimed at more efficient use of electricity in the industrial sector is the subject of a project shared between Ontario Hydro and the University of Toronto. The aim of the project is to develop thin-film electrocatalysts that have high electrical conductivity and that exhibit electrocatalytic behaviour toward oxygen. The project uses special metal targets and sputtering. Sputtering is a process that allows small amounts of ionized gases to act as electrolytes for the transfer of metal ions in controlled environments. So far, a number of new materials have been fabricated, and characterization of their properties indicates that researchers are on the right track. Successful results could lead to inexpensive and highly efficient, oxygen-reducing electrodes with the potential to provide the electrochemical industry with large energy savings.

Concerns related to improving the reliability of Hydro's aging system components, plant life extension, and nuclear plant life assurance increased in 1988. Additionally, a greater awareness of environmental issues related to radioactive and hazardous waste management, climatic change, and electric and magnetic fields emerged. Many of the Department's activities are designed to address these issues. This indicates a challenging and interesting 1989 for the Chemical Research Department.



Since 1919, when the Civil Research Department was involved in developing the revolutionary water-to-cement ratio concept for mix proportioning of concrete, it has enjoyed an international reputation for excellence and innovation. Today this reputation is maintained in the course of meeting the stringent high standards of durability and performance required for the optimal and safe performance of Hydro's hydraulic, thermal, and nuclear stations.

The Department is considered to have one of the best-equipped cement and concrete laboratories in North America. In these laboratories, world class researchers are active in developing Canadian and international standards and in testing cement and concrete for the Canadian Standards Association (CSA), the American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI).

The laboratory is equipped to perform standard and specialized tests to determine interaction between cements, aggregates, admixtures, and external environmental conditions. The Department also has access to Divisional facilities in analytical chemistry, electron microscopy, and thermal and x-ray analysis.

Since 1920, all materials to be used in concrete destined for major construction projects have been subjected to pre-testing. Ontario Hydro is the only Canadian agency that independently analyzes the quality of cementing materials. Because of the large number of potentially unsuitable sources in all areas of Ontario and Ontario Hydro's emphasis on rehabilitation programs for older hydraulic structures, petrographic and physical testing of potential concrete aggregate sources has received renewed attention. Additionally, ACI-certified concrete inspectors provide on-site inspection and testing of concrete for conformance with project specifications and quality assurance. In 1988, for example, during the construction of the Darlington Nuclear Generating Station, approximately 75 000 cubic metres of concrete were inspected. Inspection and testing services were also provided by Civil Research personnel at Cedars Channels Dam and Crystal Falls GS.

For specialized applications, such as are necessary to assess the penetration of aggressive substances through concrete, research facilities are available for the measurement of permeability and pore size distribution. Additionally, studies were undertaken to develop concretes for specific applications in hostile environments produced by exposure to temperature extremes, acids or sulphates, and radioactive wastes. Concretes for special applications such as high-density shielding, massive sections, and heavily reinforced structures were also developed.

A large, well-equipped concrete structural laboratory provides for proof testing of prototype structural components; a reaction-frame system permits an almost infinite variety of test configurations supported by servo-controlled load actuators and extensive instrumentation and data acquisition capabilities. The equipment has been used for projects as diverse as testing the effect of thermal gradients

on concrete used in nuclear stations and determining the effectiveness of shear keys in waterstops.

The Civil Research Department continues to provide consultation services and to review historical data for the Corporate Dam Safety Program. Additionally, the Department was involved in the assessment and refinement of nondestructive testing techniques for locating zones of anomalous behaviour. In situ testing techniques for assessing material properties were also pursued.

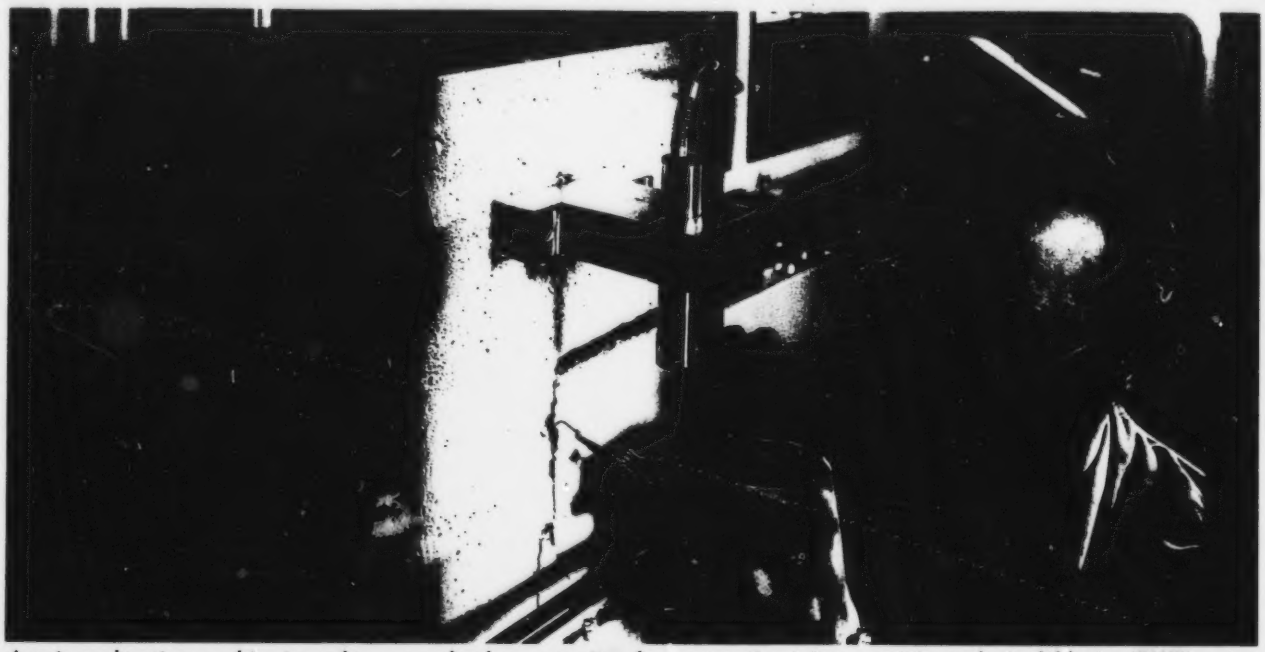
Nondestructive evaluation of the integrity of Ontario Hydro's older concrete structures is an important activity. In 1988, work was done in this area at Ear Falls GS, at DeCew Falls GS, as well as at transformer and major thermal stations. Methods of nondestructive testing included visual and microscopic inspection, ultrasonic testing, and electromagnetic location of steel reinforcement in concrete. The in situ strength of concrete was determined by the impact hammer, by Windsor probe, or by pullout tests.

Concurrent with investigations assessing the need for repair, new instrumentation was installed at R.H. Saunders GS. At this station, a void was detected at a depth of 58 metres, necessitating a new approach to the investigation of the foundation. An echo-sounding device was adapted for borehole operation and a strain gauge disc was adjusted for making measurements in the borehole. With the help of these devices and a TV camera capable of accessing the borehole, valuable investigative information, such as the shape and extent of the void as well as any surface features indicating possible dissolutioning of mineral intrusions in the rock, was obtained. The closed-circuit borehole camera was also used to investigate concrete conditions within the dams and rock conditions below the dams at Sandy Falls GS, Crystal Falls GS, and Ear Falls GS.

Dam safety assessment requires the testing of the shear strength of rock and concrete interfaces at dam foundations. At Stewartville GS and Hound Chute GS, values were obtained using direct shear equipment in the rock mechanics laboratory. An example of this technique is the use of the Soniscope to evaluate the integrity of concrete in hydraulic structures.

One innovative project of current interest is the development of a high-pressure water jetting device for cleaning plugged drains in concrete dams. Frequently drains get plugged with debris, which can lead to increased uplift pressure and potentially hazardous dam safety conditions. To counter these adverse effects, relief holes are drilled in the dam or water is applied under pressure to the drain from the crest of the dam. The concept under development in the Civil Research Department uses water jetting with concomitant high pressure (up to 35 000 psi), which is generated directly inside the drain rather than in the equipment servicing the water jetting device. Advantages of this method are greater efficiency, enhanced safety, and the ability to use higher pressure because high hydraulic pressures need not be transmitted over long distances.

Remote monitoring software developed in the Division



A universal testing machine is used to assess the shear capacity of a construction joint containing polyvinylchlorine (PVC) waterstop, which is used in nuclear containment structures to prevent leakage.

continues to be used to monitor the stability of the rock cliff situated above Ontario Power GS, as well as to monitor the drain flow at Stewartville GS.

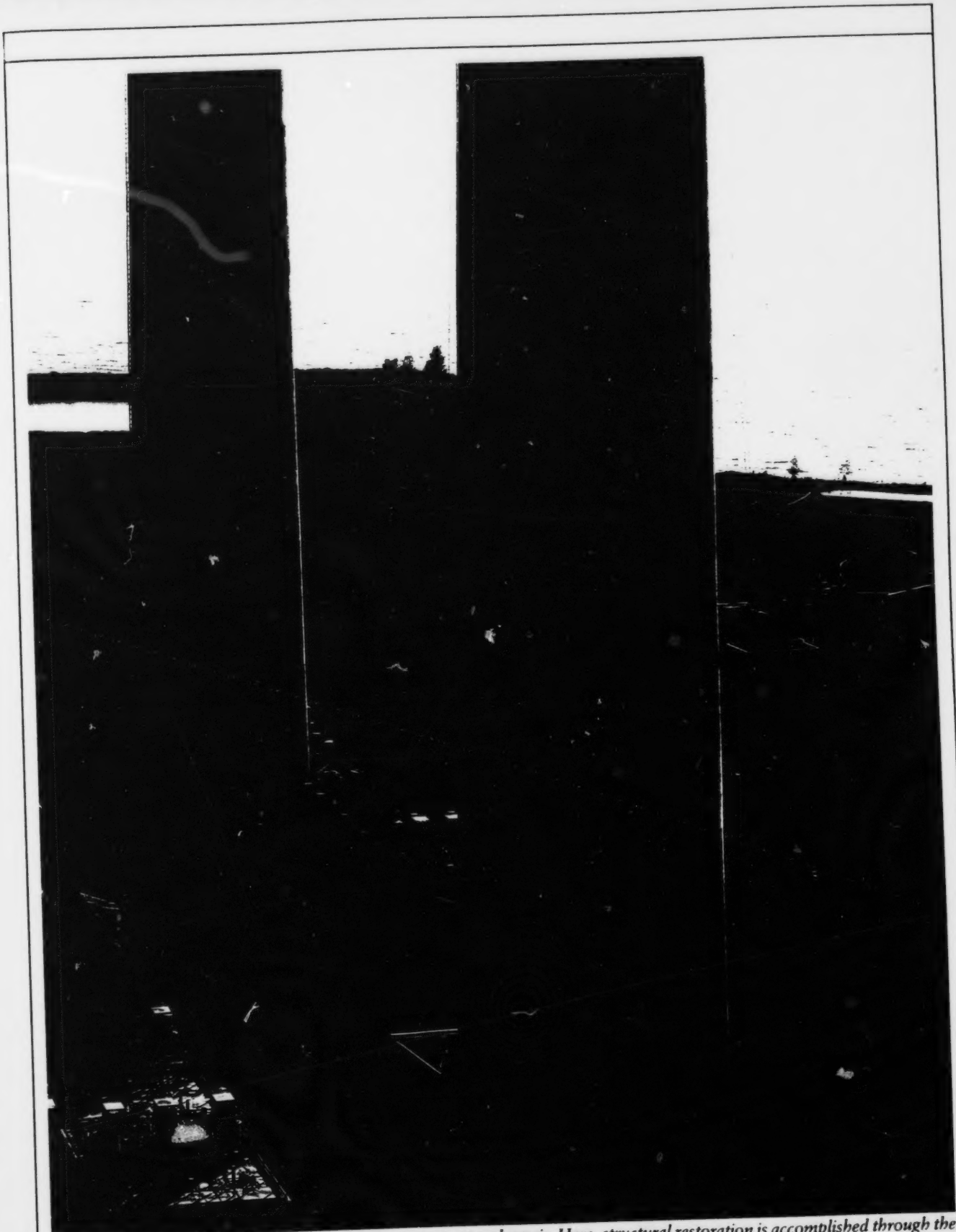
Participation in transmission line refurbishment studies included the evaluation of the condition and the load carrying capacity of foundations for transmission towers constructed more than 30 years ago. These studies provide a greater insight into the life expectancy and reliability of old lines. Probability-based calculation methods were adapted for design of transmission tower foundations.

Organic and inorganic materials, suitable for new construction and repair of structural elements of transmission tower foundations, are evaluated on a routine basis. For example, a very low-temperature polymer concrete was recently developed for use in severe weather conditions with temperatures as low as minus 25°C. Additionally, some specialized tests have been developed to meet Ontario Hydro's needs.

In the area of thermal plant waste management, the Civil Research Department continues to provide specialized geotechnical and hydrogeological research and consulting for the management of wastes and byproducts from Ontario Hydro's coal fired generating stations. Laboratory and field projects were conducted to investigate the movement of contaminants within the soil and rock strata beneath a coal ash lagoon at Nanticoke TGS. Innovative utilization options were assessed for dealing with the coal ash produced at Lakeview, Nanticoke, and Lambton TGSs. Typical approaches are the use of cement-stabilized fly ash as a potential fill material along a lake shoreline and the use of fly ash for soil amendment. Field investigations and monitoring were carried out to obtain useful data for the design of long-term fly ash mounds and for fly ash dust control. Several studies were completed with the objective of utilizing Flue Gas Desulphurization (FGD) byproducts, some of which may be produced at the coal fired stations in the 1990s. Evaluation of environmental consequences of contaminant migration and the development of waste disposal systems were the focus of much of our research in this area so as to minimize possible environmental impact from waste materials.

Civil Research Department continued to support research and development efforts related to medium- and high-level radioactive waste disposal. Through Ontario Hydro's Technical Assistance Program (TAP), which supports the waste management program being carried out at AECL and Whiteshell Nuclear Research Establishment (WNRE), studies are ongoing in the near-field heat and moisture modelling experiment. The intention of these studies is to develop a reference design for the underground disposal of irradiated fuel wastes. Additionally, studies are being carried out to investigate the hydraulic compression behaviour of shaft backfills. Ontario Hydro's technical expertise in thermal modelling was sought by AECL/WNRE for their Underground Research Laboratory (URL) experiments. These experiments are being carried out near Pinawa, Manitoba.

Although adequate methods exist for measuring the magnitude and orientation of strain, the design of underground excavations requires knowledge of in situ stress. Thus, the occurrence of high stresses in AECL's URL prompted the development, in the Civil Department, of a directional dilatometer for making in situ measurements of rock moduli. However, the rock modulus, which is a value needed for the calculation of stress, is measured in an isotropic manner rather than in relation to the in situ stress. This new instrument will enable a more exact calculation of the in situ stresses acting on an underground repository, which will in turn contribute to the increased safety of the excavation. In situ measurements obtained with this new instrument were used to optimize the siting of the long-term storage facility at Bruce NGS "B".



Cracks in chimney no. 2 of Lakeview TGS necessitate structural repair. Here, structural restoration is accomplished through the inspection of the concrete chimney, which is followed by epoxy injection.

DIVISIONAL PROJECTS:

The Divisional Projects Department creates and maintains connections between various groups within the Division, within the Corporation, and with groups external to the Corporation. The Department's work falls into three broad categories, which are as follows: new technology initiatives, research management studies, and research business support.

In the area of new technology initiatives, the Department identifies areas of interest to groups within Hydro and to external organizations. A coordination and liaison function is then carried out to further the creation of joint research projects. To achieve this cooperation, advice and resources must be drawn from within the Research Division and the Corporation at large, as well as from industry and government.

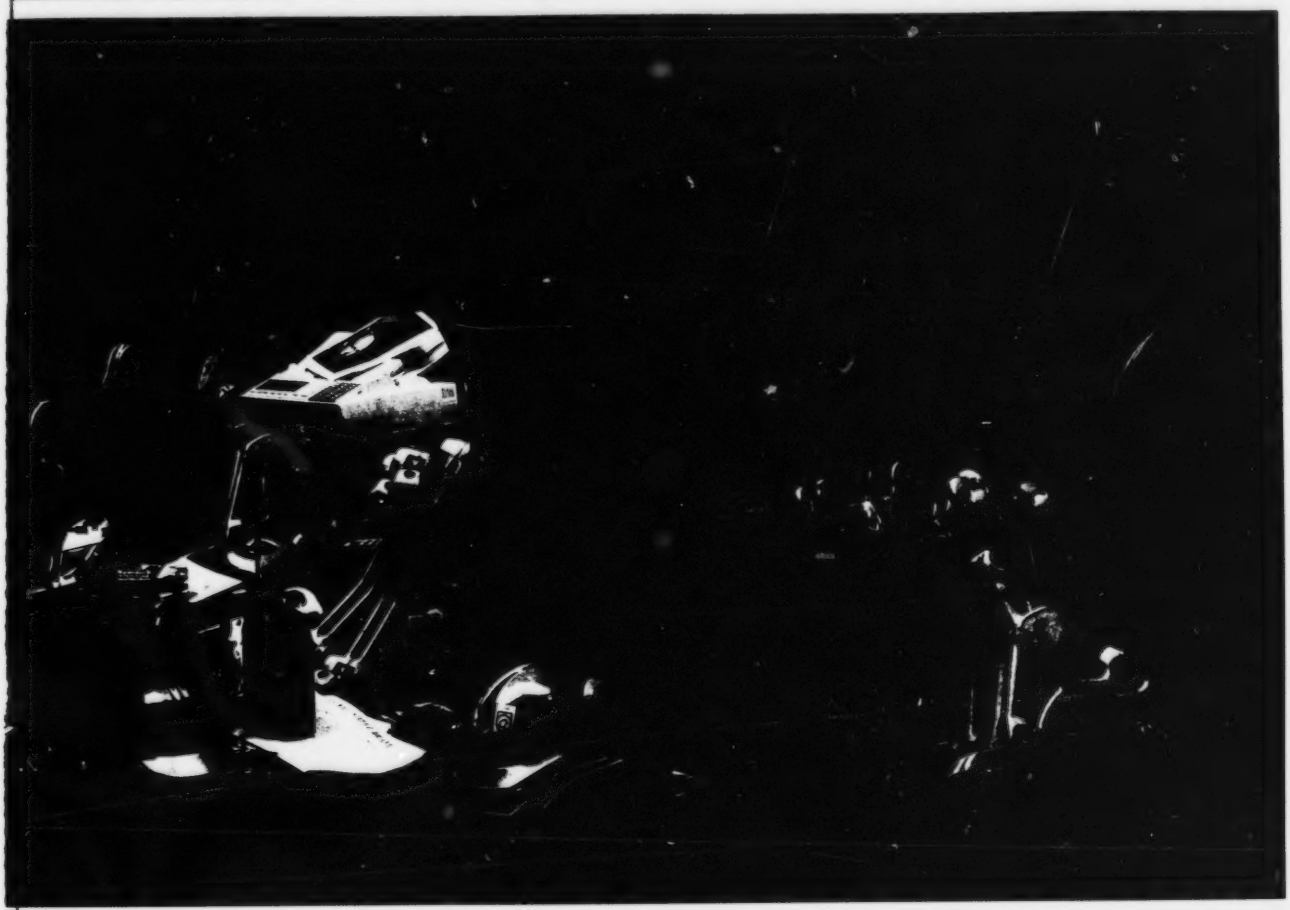
In 1988, emphasis on the Division's participation in the development of electrotechnologies of value to Ontario industry continued. Examples include coordination of the plasma arc and advanced ceramics programs. In cooperation with the Metallurgical Research Department and the Marketing Branch, a research project in process metallurgy was established. An additional program involving the Ontario steel industry was initiated, and this project works toward the production of steel with concomitant reduced CO_2 emissions.

Another initiative, started last year, was in the area of industrial laser research. Out of this research grew the creation of the Canadian Industrial Laser Association. Connections with York University and the Laser and Lightwave Centre of Excellence are being maintained, and a proposal for the creation of a Network of Excellence in the area of high-powered lasers has been submitted.

To strengthen and broaden the Department's ability to create new initiatives, one of the Division's Senior Research Scientists was given a cross-appointment between Chemical and Divisional Projects Departments. The result was the development of an initiative to look at Ontario weather data from the past. Based on these data, potential climatic changes attributable to the "greenhouse" effect will be assessed.

The coordination of, and influence over, joint research activities has been increased by having members of the Department sit on either the Board of Directors or the Industrial Advisory Board of a number of organizations. The Ontario Centre for Materials Research (OCMR), the Ontario Laser and Lightwave Centre of Excellence, the Canadian University and Industry Council on Advanced Ceramics (CUICAC), and the Advanced Materials Technical Unit (AMTU) at Queen's University are some of these organizations. The scientific and engineering excellence of the involved staff members is maintained through Adjunct Professorships held at the University of Toronto and at York University.

In February of 1988, in the area of Research Management Studies, a paper on the Research Planning Process, which was developed within the Division, was presented at the



First International Conference on Technology Management.

The preparation of the 1988 Notable Accomplishment Report was started. This report is fashioned along the same lines as the one issued in 1984, which was very well received. Reports of this nature provide an important vehicle for a research organization such as this to demonstrate ongoing contributions of value to its parent organization.

To assist in the management of the Division's activities, a number of Standing Instructions were revised; one of these concerned the patenting of Research Division inventions.

In 1988, a new and more integrated approach was taken to the creation of the Division's 1989 to 1998 Business Plan. The approach involved the Divisional Projects Department in a coordinating role. The experience gained led not only to improvements in the plan but also in the process for its preparation.

The Artificial Intelligence (AI) Newsletter, which now has a new look, continues to serve as an up-to-date information device. The newsletter is of benefit to the AI community within Hydro as well as to the community outside, and the circulation of the Newsletter is increasing steadily. Neural networks continue to represent an important advance in AI technology. As part of a Divisional initiative, a neural network AI system has been acquired and will serve as a tool to investigate its applicability to a variety of pattern recognition problems faced by Hydro.

As part of the research business support work, the Department provides assistance to the rest of the Division in the area of external contracts. This support includes the maintenance of Research Division information in a number of data bases, the upkeep of bidders lists, and liaison activities with contracting organizations. The Department also serves as a clearing house for external requests for proposals.

Again in 1988, the Department arranged over 30 tours of the Division. Visitors ranged from scientists and managers from utilities world-wide, through political dignitaries, to young high school and university students. Larger tours have also been arranged for members of scientific and technical societies. These activities are most positive in that they raise the profile of both Hydro and the Division in the eyes of the public.

The 1987 Research Division Annual Report, which contained a historical review of the Division's activities over its first 75 years of existence, is a typical example of the fine reports and brochures produced by the Department.

A number of technical information sheets, such as are typified by the REDIFAX, were produced with the help of Divisional Services Department. A new fact card targeted at visitors to the Division, Pocket Facts, was also introduced in 1988. The card is so designed as to allow it to double as a name tag.

DIVISIONAL SERVICES:

The function of the Divisional Services Department is to offer support to Ontario Hydro's Research Division. It provides services including report production; business administration; financial reporting; records, space, and safety management; printing and clerical services; model shop production; drafting; photography; payroll; and editorial services. During 1988, the Department continued to expand and upgrade its services in order to supply more efficient and innovative assistance to meet the varied needs of the Research Division.

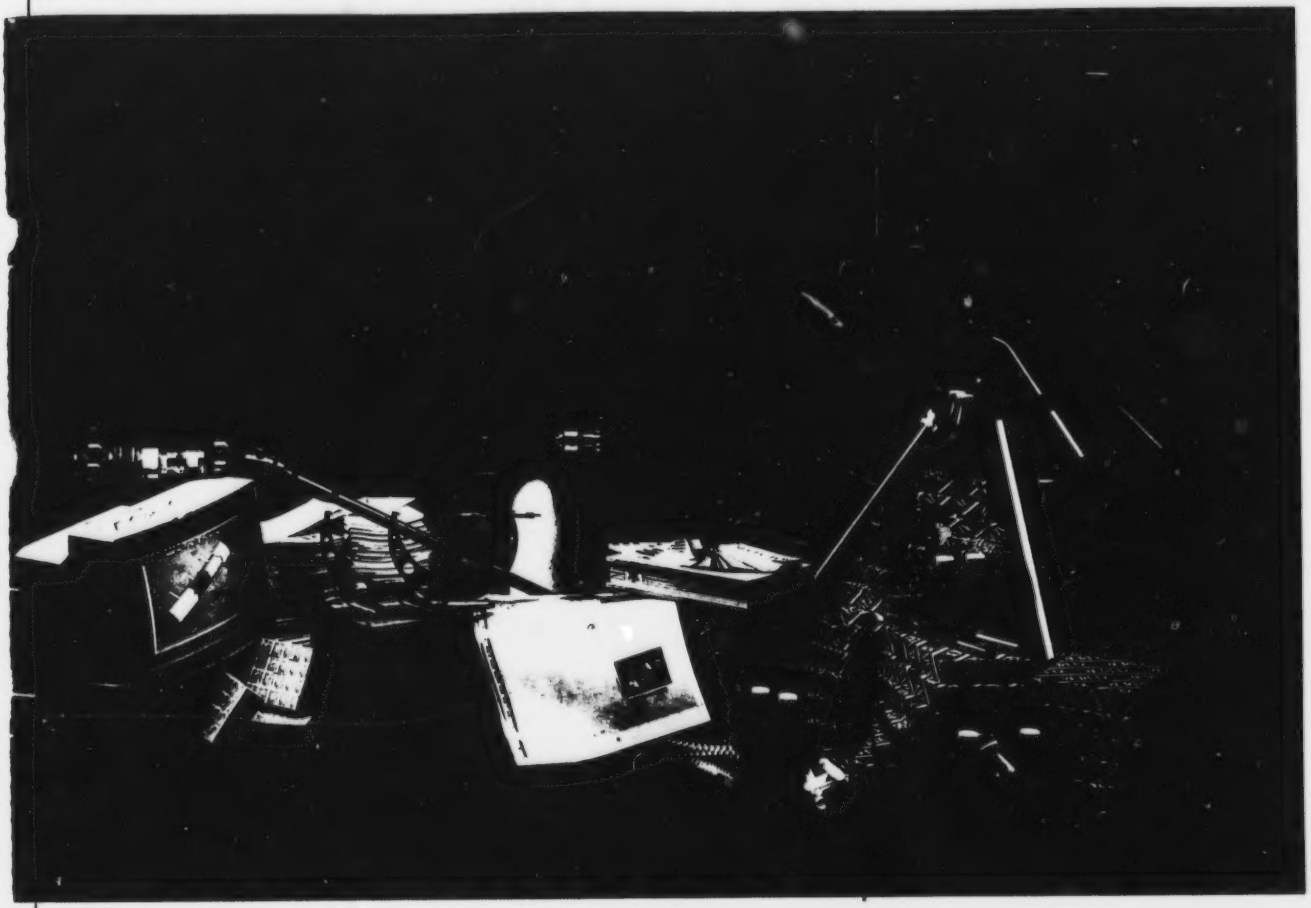
In the Business Administration Section, the Records Management Program is proceeding smoothly. All Section and Department files in the Mechanical Research Department have been converted to a standard Corporate General Subject Index and modified, when practical, to satisfy user needs. The Chemical Research Department's administrative files had all been converted to the Index by the end of 1988. Thus far, the revised file numbering system has gained popular acceptance by users. Some additional results of the new system and procedures include a reduction in filing space through the elimination of duplicate copies and older files, as well as improved access to more current files.

Recently, a medium-volume photocopier was added to the Photocopy Centre. The new machine provides a backup resource comparable to the already available high-volume copier. Both machines ensure a high-quality copy for internally produced Research reports.

This year saw the introduction of broadcast video to the Division. Video presentations have travelled to China in aid of CIDA-EPCRI, whereas more locally they have informed employees with a series on retirement planning. The productions are ongoing; in the latter part of 1988, a video production was completed that not only describes how the Division functions, but also provides a historical overview of the Division's growth and development. The video production is of particular interest in that it includes considerable original historical footage discovered only accidentally by Divisional Services personnel engaged in researching the production. This video production will be used in the orientation of new employees and in the promotion of the Division's work internationally.

One event of particular interest concerned the Photographic Services Section's involvement in recent cask-coupler impact tests. When asked by the Nuclear Materials Unit to aid in recording data during a major nuclear cask qualification test, the section responded by developing remote-controlled photographic techniques for use in hazardous environments. Cameras wired to a custom-designed remote-control board allowed film to be shot in high-speed 16-mm, 35-mm, and motion picture formats. All three formats were successful.

The Research Publications Office has had a busy year. In addition to putting out a special anniversary edition of the Research Annual, the office was involved in developing and publishing promotional material for the Division. Office staff did much of the background research necessary for the



orientation video and were responsible for the writing of the sound track.

The most recent publication to come out of the Research Publications Office is the first in a series of bookmarks designed to inform personnel of the services offered to the Research Division by the Divisional Services Department. The reverse side of each bookmark gives an anecdotal account of the contributions made to the Division by a significant Hydro figure. Other series are planned. Besides working on promotional material, the Research Publications Office provided editorial support during the compilation of the Division's Annual Business Plan and the Annual Budget. The Office looks forward to reviving the currently dormant "Research Review" as soon as possible. All aspects of the efforts of the Research Publications Office are expected to be enhanced in 1989 by the recent acquisition of a sophisticated desktop publishing system.

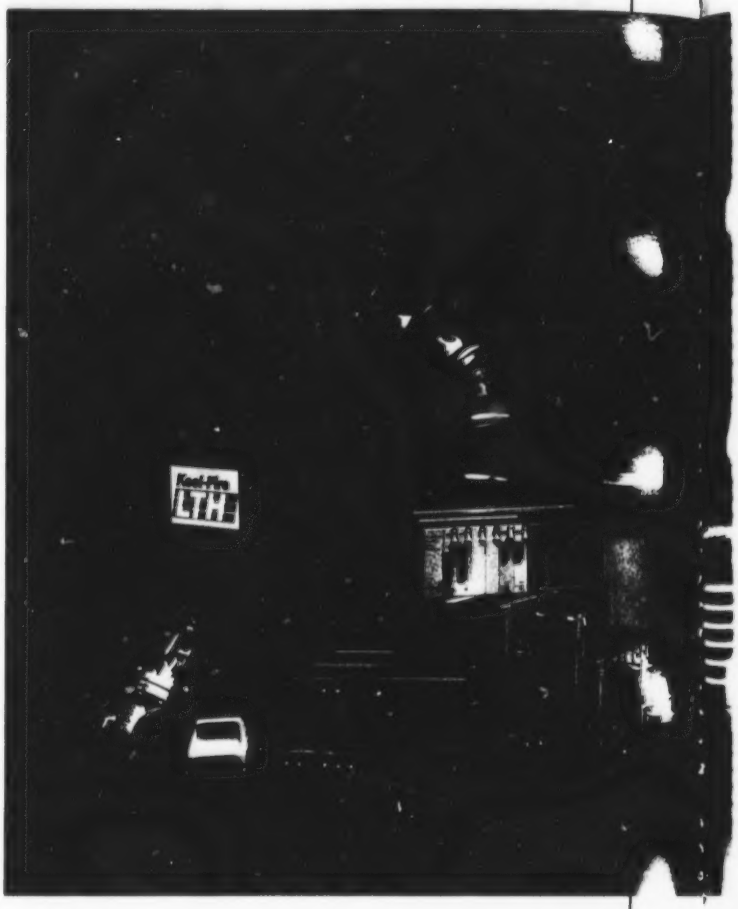
The Drafting Office's improvements, begun in 1987, are continuing. A major innovation is the extensive use nade of the Super Mac II and AutoCad systems, both of which facilitate all aspects of drafting, design, and illustration. Revisions can be done quickly, the line work and text always being clear and consistent.

In addition to its customary duties, the Drafting Office is providing designs to improve the decor and the work environment of the Division. With the aid of Building Services, a mural was executed for the Nondestructive Fracture Evaluation (NDFE) Section. The design was tailored to the needs of the laboratory personnel. Other projects are being planned and will provide additional working areas with a "face-lift". Colour schemes are being coordinated with office furniture, and photographs and mural paintings will be incorporated to reflect the work histories of particular sections.

The Model Shop has significantly upgraded its support capabilities. This has been achieved through the acquisition of new equipment, tooling, and increased interaction and feedback between customers and staff. With higher accuracy as a goal in the upgrading process, machines have been replaced, numerical control equipment has been introduced, and all machine tool axes have been equipped with linear encoders.

Within the Research Division, the facility has met many requests for the machining and development needs related to zirconium metallurgy; tritium technology; mechanical testing; applied mechanics; inspection instrumentation; material transport; and electrical, transmission, microwave, bioelectromagnetic, chemical, biological, environmental, physical science, and civil studies. Examples of these activities include the fabrication of a pressure tube burst-test facility, an ultrasonic inspection tank, x-ray-induced partial discharge apparatus, rat cage enclosures developed for the Biological Effects of Electro-Magnetic Fields (BEEF) study, microwave guides, rotators for fuel bundle inspection, ring gaps, fatigue test apparatus, fuel channel resistivity probes, and carbon-14 monitors.

ELECTRICAL RESEARCH:



Research and development activities in the Electrical Research Department are mainly focused on providing support for the bulk power system and the municipal distribution systems. The Department, which has a staff complement of 86 professionals and 67 technical and administrative support staff, is also engaged in comprehensive studies of new techniques of benefit to the Corporation and its customers in both the near- and long-term. What follows is an overview of some departmental activities of major interest.

In 1988, in consideration of the financial and environmental constraints imposed on the Corporation, a major share of the Electrical Research Department's resources was directed toward maintaining a secure power system. As part of this effort, stability control continued to play an important role for Ontario Hydro's power system, which is limited by its transmission capabilities. New power system stabilizers were installed for hydraulic generators and for the enhancement of the control systems of nuclear and fossil-fired units, thereby allowing a greater contribution to the damping of all modes of system oscillation. Further benefits are also expected from the development and validation of better theoretical models of large power system components.

Because Hydro's power system is being operated so close to its limit, it is imperative that any disturbances that do occur be analyzed and understood. To this end, a power system disturbance recorder has been developed that can record voltage and power swings during such disturbances. Data obtained with this recorder are being collected for subsequent analysis. Once stored in a computer-based system, the data can be accessed remotely over telephone lines and then analyzed with a view to implementing measures to improve system performance.

To address increasing concerns expressed by the individual as well as by commercial and residential customers, modelling studies were extended to assess the effect of arc furnaces on voltage flicker. A new modelling study, developed for the CEA, will provide an essential tool when proposals for arc-furnace installations are being evaluated.

Recognizing the need to predict and understand the performance of complex power systems, the Electrical Research Department continues its participation in an international project aimed at the development of comprehensive models of the transient performance of large power systems. Currently underway is a cooperative effort to develop and validate a transformer model.

Another analytical study, one with potentially far-reaching consequences, involves the evaluation of economic benefits that can be derived from a new low-loss transmission line conductor. The evaluation shows that, if, in the coming decades, these conductors were to be universally adopted in Canada, the reduction in transmission losses could result in significant dollar savings and deferment of several hundred megawatts of generation. Additionally, adoption of these new, compact conductors would not result in additional costs to the Corporation.

The CEA and the EPRI continue to contribute significant

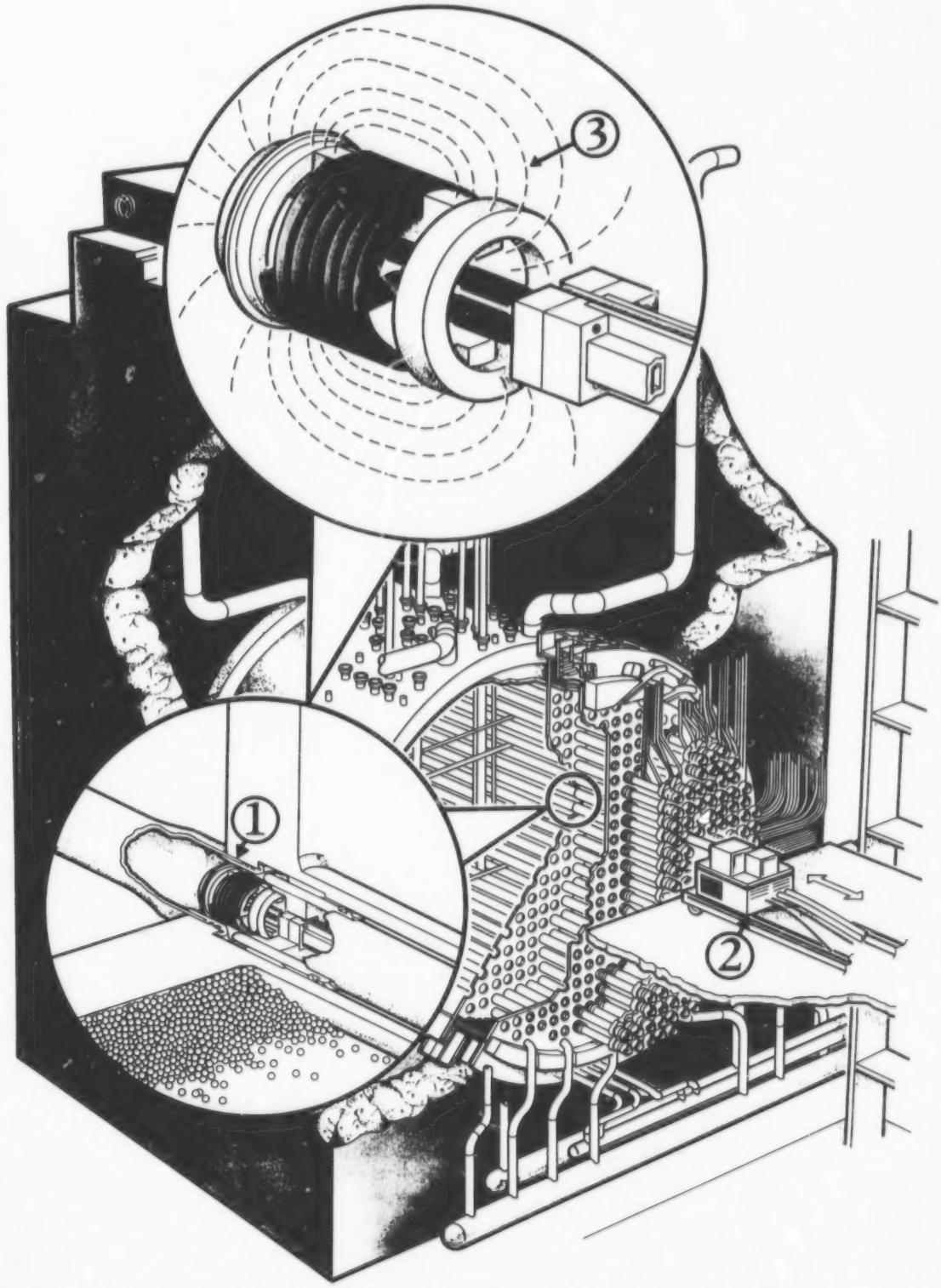
funding to Hydro's electrical R & D program. In addition, other organizations — which include the Canadian Fusion Fuels Technology Program, COG, the Municipal Electrical Association, and some American utilities — provide funding to specific research projects of benefit to both the funding organization and Ontario Hydro. Whereas most of these externally supported studies addressed near-term problems, longer-term concerns are receiving increasing attention.

One area of theoretical research, the introduction of artificial intelligence to power system operation and maintenance, shows great promise. In addition to the Generator Expert Monitoring System (GEMS) now being developed for EPRI, other useful explorations focus on intelligent mobile robots with applications for maintenance in hazardous locations. This latter project is collaborative, involving AECL, the University of Toronto, and York University. Most of the funding will come from Precompetitive Applied Research Network (PRECARN) Associates, a non-profit consortium of Canadian industrial companies.

Whereas better analytical techniques are becoming increasingly important in deriving maximum benefit from new technologies, much attention is focused on the performance and improvement of power system components. Currently, the Electrical Research Department is participating in a multidisciplinary research program with the Chemical Research Department, the Metallurgical Research Department, AECL CANDU Operations, and AECL Research Company to assess a new technology with the ability to detect and locate minute leaks in reactor pressure tube systems. The project, which is funded by COG, is currently involved with assessing the ability of state-of-the-art diode lasers to detect heavy water via absorption spectroscopy.

Of continuing interest is the behaviour of high-voltage insulators under severe weather conditions. Studies on insulator behaviour began in 1986 as a response to serious concerns about the reliability of the power system under specific weather conditions. At that time, the performance of high-voltage insulators used in transformer stations and on 500-kV transmission lines was studied both during and after ice storms. Now, in cooperation with the Power System Operations Division, the program has been expanded, and stations and transmission insulators are tested in a wider range of simulated weather patterns. The objective of this broader study is to establish well-supported performance characteristics that can then be used in the making of operational decisions about "safe posture" procedures needed to ensure secure power delivery under adverse conditions.

To ensure experimental repeatability and to permit accurate formulation of new test standards, much attention was given this year to making improvements in the design and operation of the Division's High-Voltage Laboratory's test chamber. Now the chamber can accommodate careful control of temperature, humidity, precipitation rate, droplet size, wind speed, and wind direction. This upgraded laboratory, with these highly specialized climate controls, is now in continuous use and will likely become essential for establish-



The process of removing a calandria tube in a CANDU reactor is as follows: The rolled joint (1), which holds the calandria tube firmly in place, is rapidly heated but cannot expand in the cold surrounding tubesheet. After cooling, the calandria tube shrinks and can be readily removed. The carefully controlled "shock heating" process is performed with a mobile high-frequency power supply (2) and a water-cooled induction coil (3).

A 500-kV load break interrupter is undergoing a bias voltage test.

ing new insulator test specifications and for developing new insulation designs to meet winter performance specifications. The absence of a meaningful winter performance specification for high-voltage insulators at present can be attributed to the lack of adequate testing facilities.

Whereas outdoor insulation reliability is mostly a concern of northern climates, the performance of enclosed high-voltage insulation systems is receiving increasing attention among all major utilities. During the past two decades, many promising, but untried insulation techniques have been introduced in power equipment and underground cables. In general, manufacturers, as well as utilities, have moved cautiously; in final analysis, however, only operating experience itself can establish the success of new technology. This is particularly true for highly stressed compressed-gas insulation systems that are used in switchgear at voltages of 230 kV and above. To reduce the risk of unexpected operating problems as much as possible, Ontario Hydro has maintained an ongoing research program to assess the performance of SF_6-gas-insulated switchgear and bus ducts during the past 15 years.

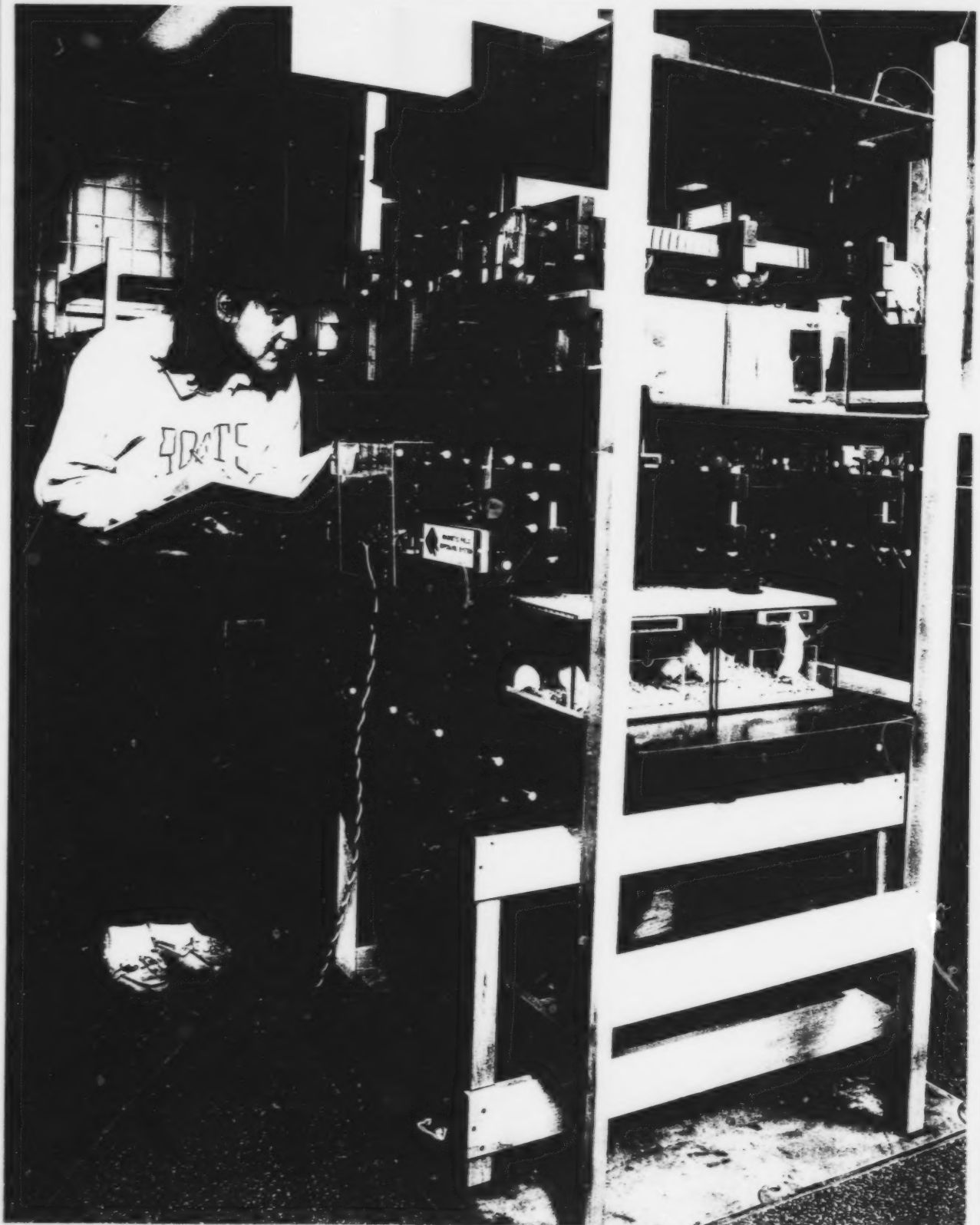
Several recent investigations, which were carried out under contract to either CEA or EPRI, resulted in better specifications for acceptance testing of new equipment and for identifying potential failure mechanisms. A current research project on the reliability and life expectancy of spacer insulators in compressed-gas bus ducts is aimed at identifying and analyzing aging mechanisms in the filled polymers used in these insulators. This study, which is co-funded by EPRI, will provide the basis for the development of ultra-sensitive diagnostic techniques for the early detection of insulation weaknesses.

Following the development of an on-line technique to monitor degradation processes in the insulation of hydraulic generators, attention became focused on thermal generators not readily able to accommodate recently developed and necessary instrumentation. This new initiative, supported by CEA, addressed several serious technical difficulties. Promising results are being obtained. The feasibility of instrumentation for monitoring generators at nuclear and fossil-fired plants has been demonstrated, and this is expected to become available in the near future.

Electromagnetic phenomena of benefit to Ontario Hydro's Corporate Nuclear Program and Industrial Marketing Department, as well as to industry at large, are studied and harnessed in the Electromagnetic Laboratory. Some applications produced by these efforts well suit the repair and assembly of nuclear reactors. The resulting savings to the Corporation are substantial.

The induction coil, illustrated in this overview of the Electrical Department's activities, was developed in this laboratory. The rapid induction heating process allows the separation of calandria tube and pressure tube rolled joints in CANDU reactors. The process reduces the tube diameter, which makes possible the removal of tubes without significant mechanical force. Future research will focus on the development of remotely operated equipment for use in the rehabilitation, repair, and decommissioning of nuclear facilities.

Power system protection continues to be an area of major interest. The increased use of Application Specific Integrated Circuits (ASICs) in equipment being developed for application in protective systems is providing functional as well as economic benefits. In one case, the circuitry required for three different projects was combined into one ASIC, thereby resulting in a significant cost saving. Additionally, an ASIC was designed to upgrade the performance of the widely used (about 1 000 units installed per year) HTDX timing relay. This one relay now provides digitally controlled time delays of up to 40 minutes and adapts automatically to battery voltages from 40 to 280 V. The evaluation of protective relay systems for series-compensated lines moved into high gear with the development of both hardware and software to support the testing program. Several evaluations of new relays and systems were carried out for the Corporation as well as for other utilities. A new stator ground relay, developed in 1986, was installed on all units at the Lakeview Generating Station. In cooperation with several



Exposure systems for Ontario Hydro's Magnetic Field Rodent Reproductive Study (MFRRS) were supplied by Research Division. This experiment, which was designed to address the concerns of video display unit operators, is currently being performed at the University of Toronto.

Divisions in Ontario Hydro, a program to conduct research in digital communications has been initiated; this option is becoming increasingly attractive for supporting reliable protection and control systems. In concert with this development, work on novel protection schemes that take advantage of high-speed digital communications has been reactivated.

The compatibility of power lines with communications facilities continues to be important. Preconstruction electromagnetic interference surveys were completed on routes for new 500-kV lines as were investigations related to broadcast signal re-radiation. Another area of concern is the possible interaction between power-line carrier and navigation facilities. This is the subject of an ongoing study carried out for CEA.

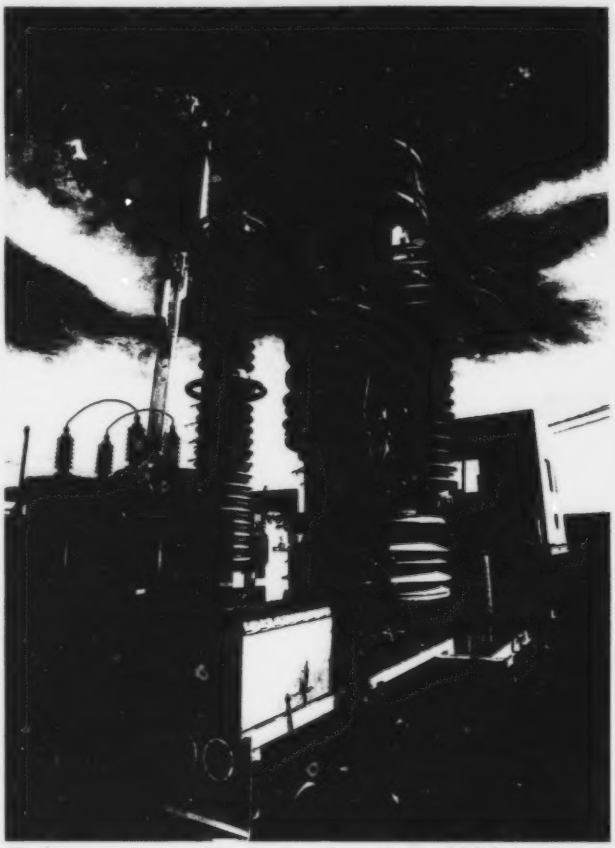
Several distribution system studies were undertaken as part of a program to increase technical support for municipal utilities in Ontario. Of particular interest is a CEA-funded project that addresses issues concerning transformer security and reliability. This particular study, initiated in response to concerns about equipment failures that could be violent, analyzed the ability of oil-immersed current-limiting fuses in transformers to withstand electrical and mechanical impulses. The outcome was the development of carefully controlled test procedures to be included in standard specifications to ensure that new fuse products can safely withstand normal field occurrences. It is interesting to note that the experience gained in this study also yielded recommendations for improvements in fuse design. Recognizing that 90 percent of customer interruptions can be traced to failures in the distribution system, Ontario Hydro and the CEA initiated a joint project to examine the effects of lightning on the reliability of distribution networks. The study involves the correlation of lightning activity with system outages, which allows identification of those components and system configurations most susceptible to failure during lightning storms.

Following the issue of a CSA standard on gapless metal-oxide surge arresters for alternating current systems, a comprehensive application guide for distribution surge arresters was completed under contract to the CEA. This guide, which recognizes different design philosophies, is the first of its kind in the industry and is intended to help distribution utilities in designing surge protection for systems operating at 2.4 to 50 kV.

With the upsurge of interest in time-of-use rates as a load management incentive, a need to assess the suitability of metering equipment available for this new rate structure in the commercial and residential market became apparent. The assessment revealed that, although little is currently available with the necessary Canadian approvals, manufacturers are responding to Ontario Hydro's expressed interest. It is expected that new Canadian approved metering systems will soon appear.

The efficient use of electricity can produce benefits for Hydro's customers and for the power system. Both residential and commercial customers can lower their heating bills by using either bivalent (propane/electric) or ground-coupled heat pumps while reducing demands on the power system by 50 percent when compared with standard electric heating. This year the performance and reliability of these systems have increased.

In 1988, water heating systems also received attention. Demonstrations of efficient systems continued for commercial applications that reduce power demands by at least 40 percent while they improve working conditions in restaurant kitchens and laundries. A unique water heating manual, which covers the theory, equipment, methods of sizing, installation, and maintenance of water heating systems, was prepared for the CEA. This manual has received world-wide attention and is becoming an indispensable tool for utilities, designers, and users.



Technicians are in the process of erecting a 700-kV resonant test set for calibration before testing gas-insulated stations.

The Department continues to assist industrial customers determine the benefits of using dehumidification, microwave, infrared, lasers, and various other electrotechnologies in their production facilities, the objective being to reduce energy costs, to improve productivity, and to enhance competitiveness. Working with energy management personnel from both the Regional and Head Office, the Electrical Department was able to provide over 60 industrial customers with complete technical and financial evaluation packages. These packages were based on the results of both laboratory and analytical work. A study done by Central Region showed a high implementation rate of these electrotechnologies by industry with 20 percent of the research projects implemented and another 30 percent currently under active consideration. Overall, the Electrical Department's collaborative and individual efforts to effect the more efficient use of electrotechnologies, for the benefit of the customer and the Corporation, yielded successful and promising results throughout 1988.

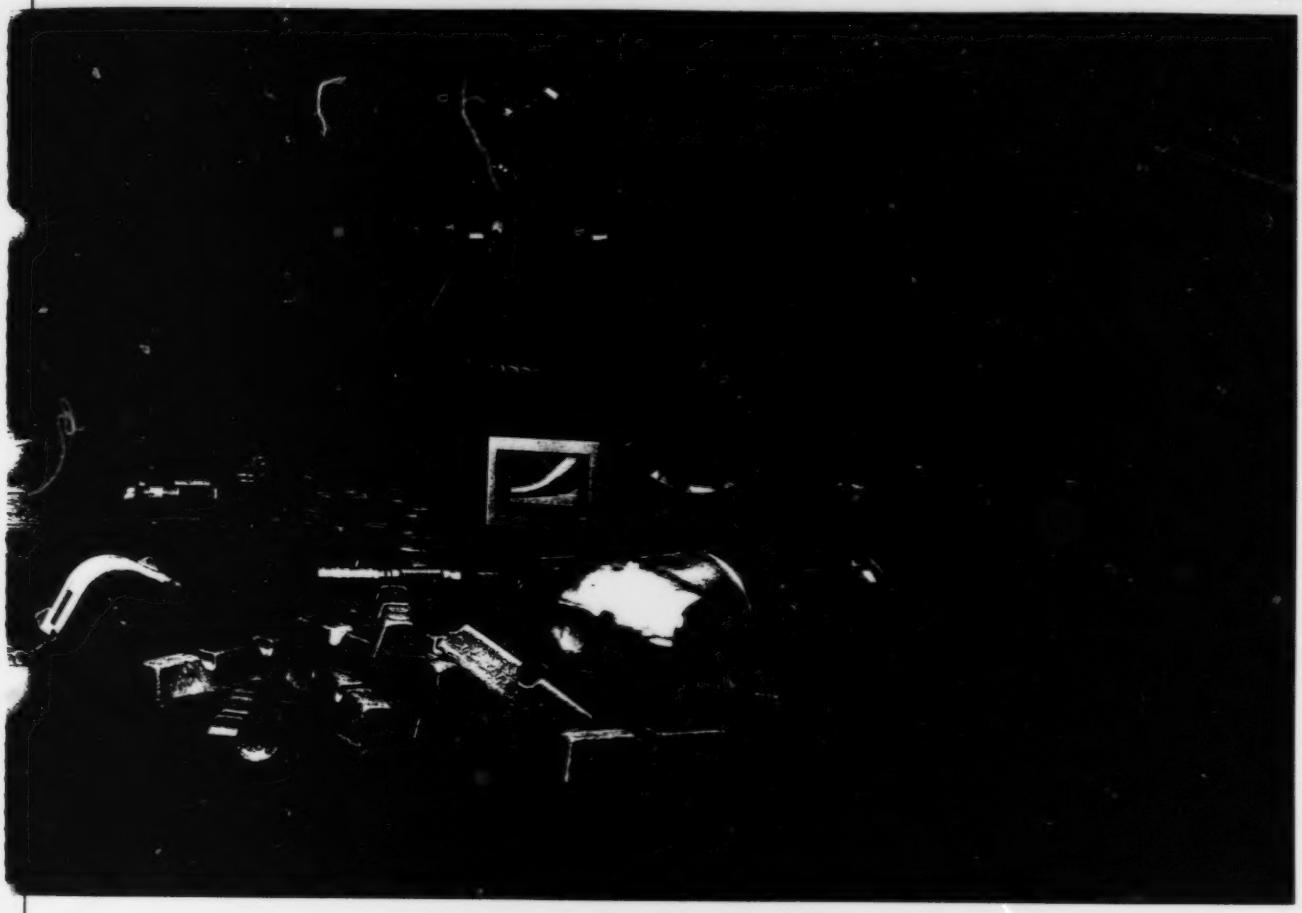
MECHANICAL RESEARCH:

The Mechanical Research Department's work activities through 1988 provided strong support to the Nuclear and Transmission System Program areas. Support activities involved provision of testing services and technical investigations, problem solving, and research studies performed in support of safety and reliability issues.

To verify safe and reliable behaviour of equipment, structures, and components, both modelling and full-scale tests were used. In the environmental qualification field, one highlight was a steam-environment qualification test of a heat-transport pump circuit breaker. These breakers are required to trip pumps off line under various postulated accident conditions. One such condition occurs when a main steam-line breaks. Under these circumstances the circuit breaker and its control cabinet become enveloped in low-pressure steam. Direct testing in the laboratory demonstrated that the breaker could successfully trip the pumpset. Many smaller components that perform electrical, instrumentation, and control functions were also tested during the course of the year, thereby contributing to the analysis and engineering of nuclear plant safety.

The Department's Applied Mechanics Section is currently involved in the development of safe methods of storage, transportation, and ultimate disposal of high- and low-level nuclear wastes. Under development are a tritiated heavy water transportation package, an irradiated fuel transportation cask, a concrete integrated container for transportation and storage of used fuel, and iron based stressed shell (IBSS) and thin walled particulate packed (TWPP) containers to be used for the ultimate disposal of irradiated fuel. Nine-metre drop tests and extensive finite element analyses have demonstrated the impact resistance of the tritiated heavy water transportation package, and on the strength of this work, a transportation license has been obtained from the Atomic Energy Control Board (AECB). Tests of impact and of fire resistance under accident conditions have demonstrated the integrity of the container intended to transport irradiated fuel. Additionally, an extensive program related to the concrete integrated container is underway. The work program includes finite element analysis, drop tests, and fire tests. The development and testing work related to TWPP and IBSS containers for the ultimate disposal of irradiated fuel is progressing well. The Section staff have provided a lead role in coordinating Research Division's efforts related to the containment and immobilization of irradiated fuel.

The Corporate Business Plan for 1988-1997 identifies deterioration in the reliability of Ontario Hydro's transmission system as being of major concern. This deterioration, which has occurred over the last few years, is due to the lack of sufficient resources for maintenance aggravated by the effects of aging. Almost one-third of the total circuit kilometres of Hydro's transmission lines are more than 40 years old. It is estimated that the incremental cost to customers in 1987 due to this deterioration was in the order of 10 to 15 million dollars. As a result, major replacement and refurbishment programs must be undertaken.



In 1988, to begin the refurbishment process, a program with a budget of $1.75 million was approved and carried out. The program, which involved Design and Construction Branch and several Departments of the Research Division, comprised a cooperative effort to assess the condition and residual strength of 115-kV Kingston towers, line hardware, conductors, insulators, and foundations on a line south of Smith Falls. A short section of the line, which was built in 1929, was in the process of being rerouted. Three towers that were scheduled to be replaced were tested to destruction in the field. Also, a number of grillages and rock anchors were completed, along with laboratory tests on the insulators, conductors, and line hardware. The results of these tests indicate that this line is in good condition. Further tests on other lines are scheduled for 1989.

Other activities in the transmission system area included the evaluation of fibre optic overhead groundwires. Cables from various manufacturers were evaluated to determine their fatigue strength and performance under galloping and aeolian vibration loads.

Studies related to the control of vibration of overhead lines are continuing. Independent statistical analysis revealed that the average amplitude attributable to ice on four-conductor bundle lines can be reduced 17 percent by addition of detuning pendulums. Dampers for aeolian vibration control and spacer dampers to control wake-induced and aeolian vibration of bundle conductors are undergoing comparative damping measurements to assure reliable protection against conductor fatigue in the field. A CEA-sponsored program to determine the wind energy transferred to bundle conductors with various configurations was completed in cooperation with the University of Toronto. The project demonstrated the possibility of alternative bundle conductor arrangements that would suffer less vibration and fatigue than do present designs.

An important facet of the Mechanical Department's work program concerned the technical investigation and resolution of problem solving issues related to efforts to improve plant equipment reliability and reduce operating costs. Contributions to the resolution of several major vibration-related problems affecting piping systems at the Pickering and Darlington NGSs were made. New and revolutionary methods, such as one that analyses the direction of vibrational energy flow in piping, were used to identify the sources of vibration. The method, which was developed in the Fluid Dynamics Laboratory, contributed to design modifications that solved the problem.

A number of problems related to rotating equipment and structural vibration in generating plants were corrected. Methods based on experimental and theoretical rotor and structural dynamic analysis were used to identify the causes and to determine effective and economical solutions.

The introduction of new, and the expansion of existing, computer-based condition monitoring systems in a number of generating plants is progressing. These systems provide maintenance personnel with useful information about main-

Greg Morandin, a technologist in the Applied Mechanics Section, is collecting data that will be used in the development of transportation containers for irradiated fuel.

tenance requirements. The result is greater equipment reliability at less cost, since required maintenance is done in a timely manner, and any unnecessary maintenance is eliminated. Research is in progress to improve the diagnostic capability of these systems by the use of advanced signature analysis techniques, expert systems, and neural networks.

Consultative and technical services were provided to groups both internal and external to the Corporation. Noise assessments and controls for power transformers, reactors, and cooling fans at transformer and distribution stations were some areas of recent concern. Improvements were made to equipment and methodologies, and these now enable the surveying and predicting of noise levels in the vicinity of transformer stations. Noise levels vary because of different configurations of layout and acoustical treatment of the walls of the enclosure.

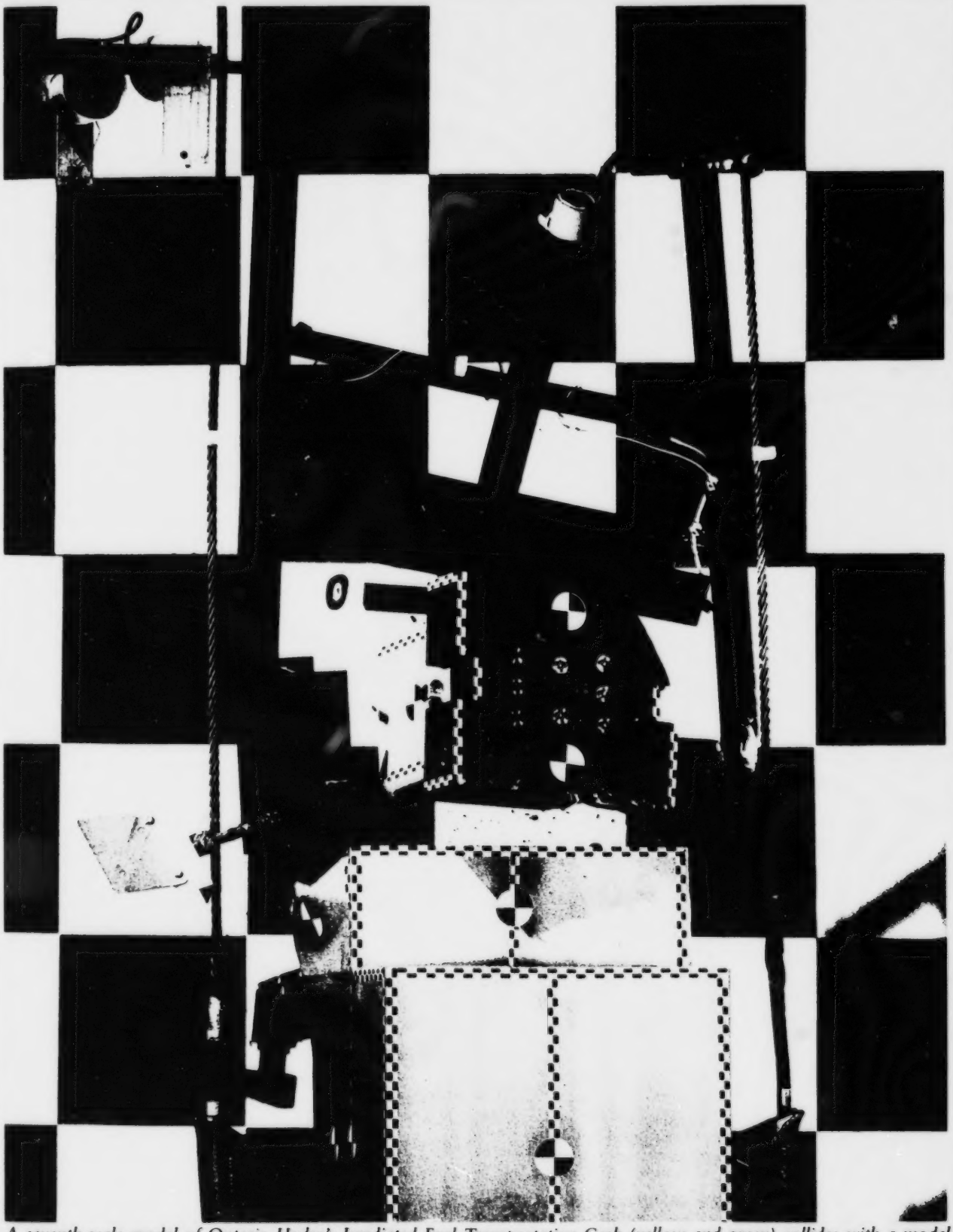
An ongoing study on audible noise emanating from the single circuit transmission line (corona noise) was expanded to include a double-circuit 500-kV line at a site near Milton. A technique was developed for automatically monitoring and collecting information from occurrences of corona noise. The technique is capable of differentiating corona noises from other sources of noise such as are produced by weather conditions. The technique is proving to be reliable over a wide range of meteorological and background noise conditions.

Some of the Department's research and development activities feature work on aerosols and aerosol transport. Further data were collected for the Steam-Water Iodine-Partitioning Experiment (SWIPE). The objective of the experiment is to determine how radioactive iodine "partitions" between liquid and vapour phases in a flashing water jet. Also addressed, both theoretically and experimentally, was the physical transport of aerosol particles by flow within containment. These studies are important because partitioning and transport are key links toward improving estimates of potential radioactive leakage under accident conditions.

Another research project seeks to develop methods for monitoring the condition of primary heat transport (PHT) pumpsets by means of vibration analysis.

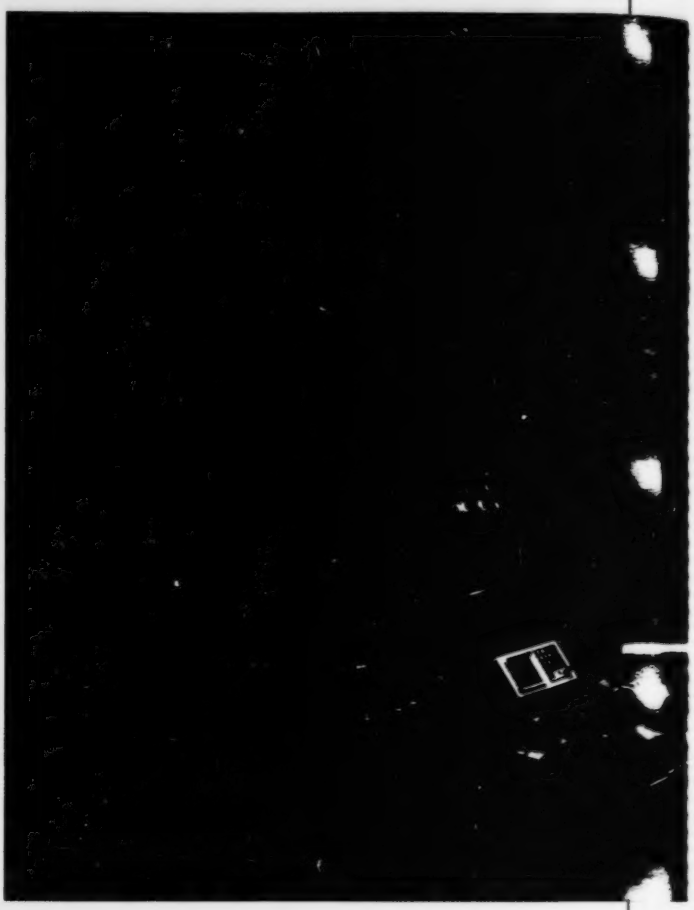
Study continues on the finite element analysis of hydride blister formation in CANDU reactor pressure tubes. Two- and three-dimensional mathematical models are being developed to predict hydrogen transport and blister growth and to indicate the useful life of pressure tubes under a variety of service conditions. Another project related to pressure tubes is one in which modifications are being made to Creep Degradation Evaluation in Pressure Tubes, Hydro (CDEPTH), a computer program for predicting pressure tube creep and elongation. The modifications will allow direct comparison of analytically predicted results with in-reactor measurements. The Department has also been active in the large-scale fuel-channel replacement program at Pickering NGS and in rehabilitation programs such as the West Shift Operation at Bruce. Construction of the Burst Test Facility for doing pressure tests on large vessels, pressure tubes, and piping components is now complete. The commissioning tests on the facility are expected to be completed by the end of 1988. The facility will also be used for the "leak-before-break" work program related to the Darlington PHT piping system.

The demand for the Department's services to solve nuclear plant component integrity problems continued to be high in 1988. Examples included those related to the Bruce Nuclear Generating Station's de-aerator vessel, Darlington's feeder pipes, Pickering's spacer rods, and other generic steam generator problems. The staff also played a lead role in a number of multidisciplinary programs that arose as part of the Nuclear Plant Life Assurance Program, the acquisition of naturally aged material and component samples from the decommissioning of the NPD, and the investigation of the long-term effects of the load-following operation on the reliability of nuclear plant equipment.



A seventh-scale model of Ontario Hydro's Irradiated Fuel Transportation Cask (yellow and green) collides with a model locomotive (gray). To achieve a 65-mph collision, the cask model was accelerated with a rocket motor as it fell.

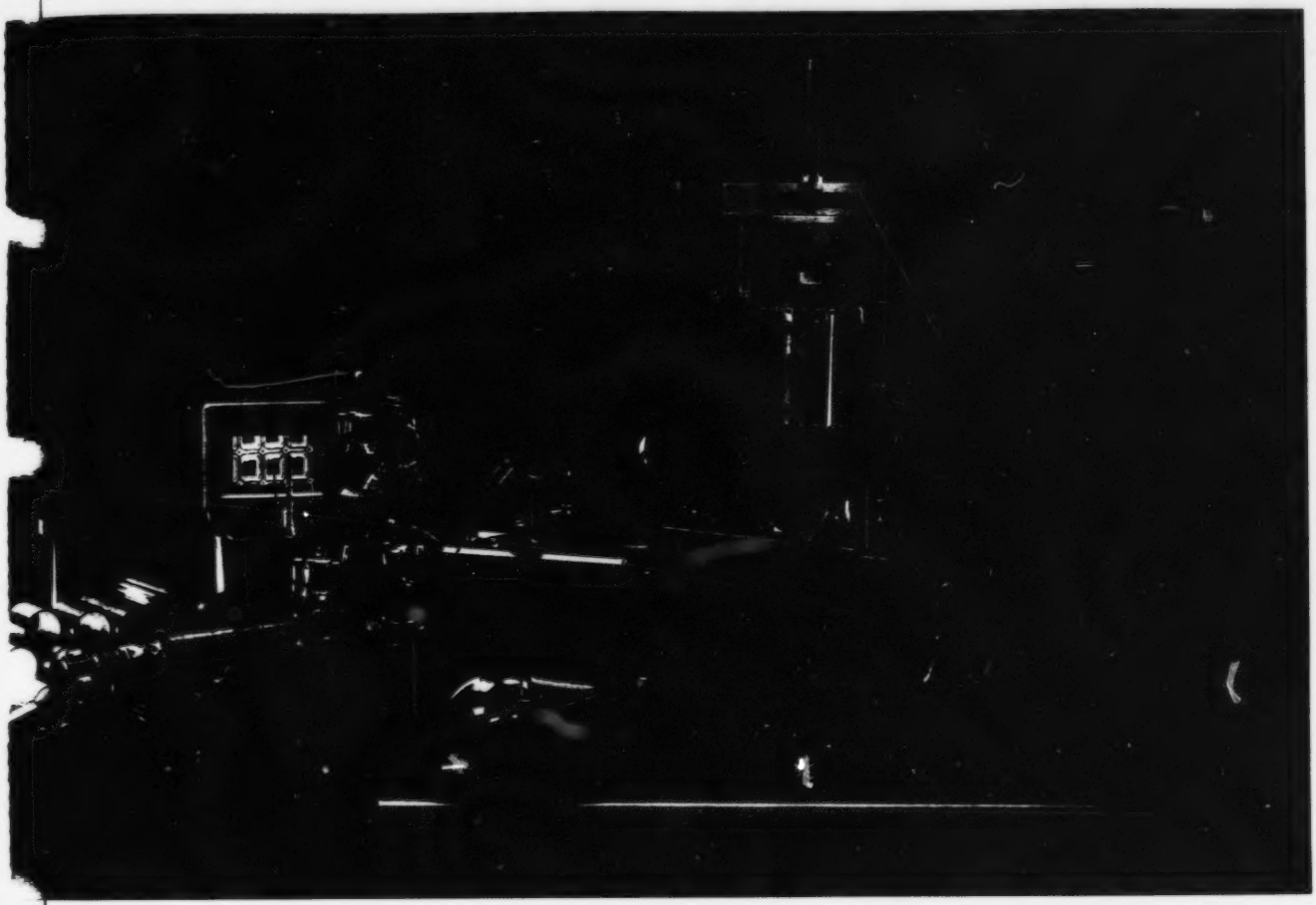
METALLURGICAL RESEARCH:



The metallurgical discipline comprises many diverse technologies, ranging in scope from metal physics to extractive metallurgy. The work of the Metallurgical Research Department, therefore, covers a number of disparate technical areas. For example, fracture mechanics and nondestructive evaluation are two very different technologies, yet, in context of this discipline, they are complementary. In fracture mechanics, metallurgists seek to predict the performance of materials, components, and structures through both analysis and experiment; in nondestructive evaluation they attempt to discover imperfections that may lead to a structure's early demise. The two technologies meld, however, when considering the impact of a defect: nondestructive evaluation is the means through which the defect is discovered and described in spatial terms, and fracture mechanics is the route through which this information is used to determine the repercussions of the defect's presence. Neither technology, however, is limited to the narrow bounds of defect-structure interaction.

The prime thrust of the Department's work program is in support of CANDU technology. The work is balanced in terms of forward looking research (long-term); shorter-term research, primarily funded by COG; and technology transfer to groups such as Central Nuclear Services (CNS) and Design and Development — Generation Division. The work is divided among four sections, namely Materials Integrity, Corrosion & Tritium Technology, Metallurgy, and Nondestructive and Fracture Evaluation.

The Materials Integrity Section utilizes analytical and test techniques designed to investigate factors controlling the deformation (irradiation-enhanced creep and growth) and fracture (delayed hydride cracking) aspects of core components in CANDU reactors, particularly the zirconium-niobium pressure tubes. An important part of these studies is to achieve end-of-life conditions in the specimens in advance of actual in-service components. With respect to irradiation, this is achieved by testing in high-neutron flux reactors, which are available in the United Kingdom and France. Data resulting from these tests will provide input useful in the development of design equations and additionally will establish which microstructures in pressure tubes could result in a reduced in-service deformation rate. In fracture-related studies, concentrations of hydrogen are increased to suspected end-of-life levels. Crack nucleation and growth are studied, and the influence of both metallurgical and operating parameters on these processes is evaluated. A specific nucleation mechanism, currently the focus of significant attention, concerns the formation of hydride blisters on the outside surface of the pressure tube. Detailed studies of the growth of these blisters have been performed, and tests to determine the size of blister able to nucleate a crack have been carried out. The objectives of these fracture and deformation studies are to develop predictive capabilities such that reactor maintenance can be properly planned; to ensure that no unwelcome surprises occur during in-service performance of pressure tubes; and to identify how the microstruc-



ture of pressure tubes could be modified to give improved in-service performance.

An important initiative of the Corrosion and Tritium Technology Section is focused on establishing a detailed understanding of the principal source and ingress routes of deuterium into the zirconium alloy pressure tubes. Eventual control of hydrogen levels, to keep them below those levels that will cause fracture problems, is the expected result of this research. It has been established that corrosion of the alloy by the heavy water coolant is one ingress route. A normally protective barrier of oxide film keeps deuterium ingress rates low, but when the film's protective qualities are damaged or lost, accelerated ingress may result. Laboratory tests to establish the precise role of temperature, oxide features, and surface properties on the corrosion process are in progress. Extremely high-resolution state-of-the-art imaging, surface analysis, and electrochemical methods are being used.

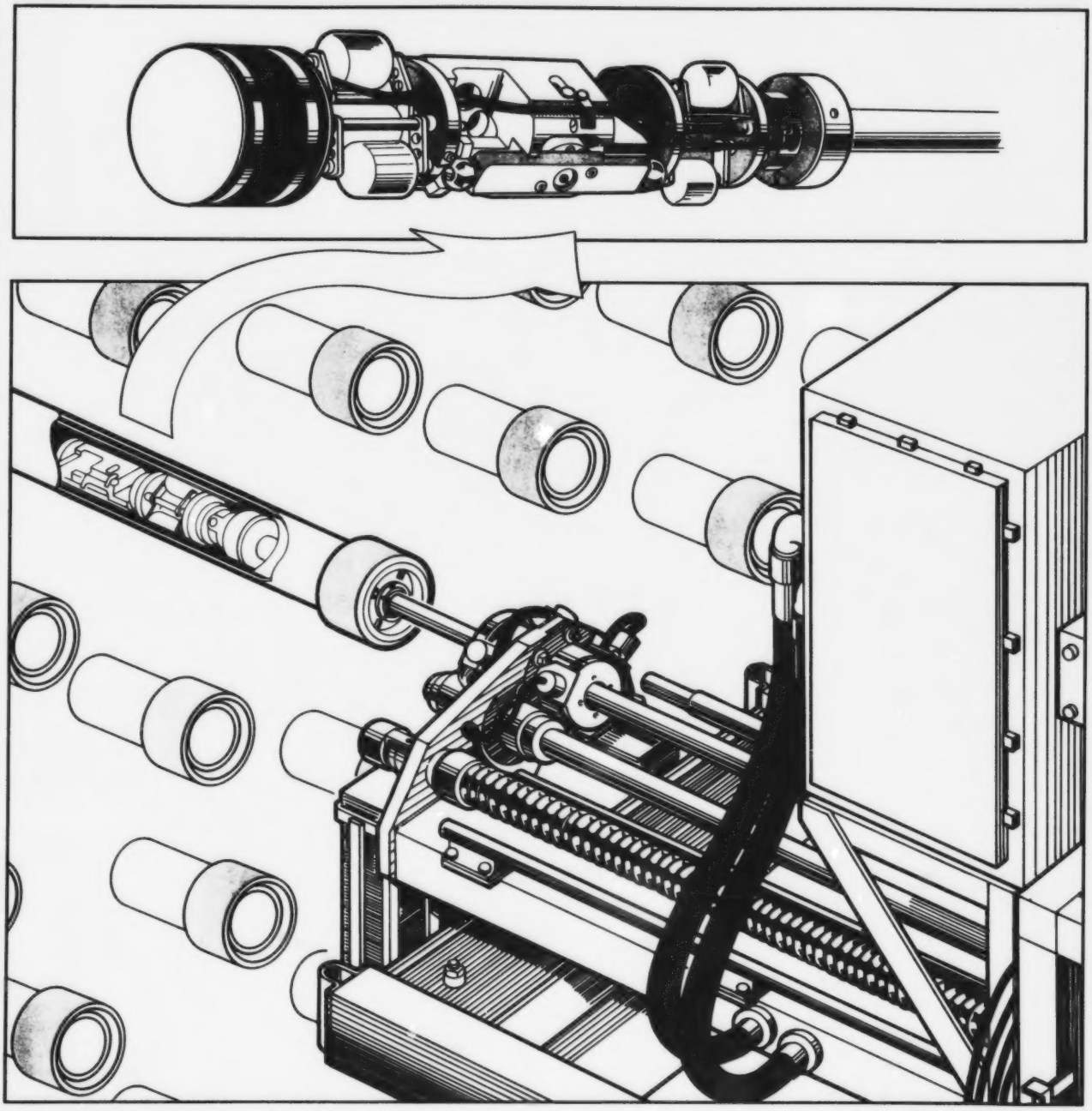
Other possible ingress processes are being evaluated, and these involve interaction with the gas annulus environment and study of the microstructural changes in bulk alloy that occur as a response to in-reactor aging. Additionally the correlation of reaction kinetics and reaction products with deuterium absorption is being explored under simulated reactor conditions.

Fracture mechanics technology is extensively applied in support of the Corporation's nuclear generation program. A pressure tube burst-test facility has been commissioned and is being used to study the fracture of pressure tube sections exhibiting surface cracks. Tests performed in the facility will supplement small-specimen tests currently being performed to investigate the effects of hydride structure on tube fracture toughness. A high-pressure and high-temperature autoclave is being commissioned and will be used to fatigue-test zirconium-niobium specimens in an operating environment.

The Nondestructive Evaluation Unit's principal involvement is also with fuel channels. The complexity of current nondestructive evaluation technology demands an integrated multidisciplinary team approach. Thus, in addition to involvement in the primary technologies of acoustic emission, eddy current, ultrasonics, and spatial measurements, the team relies heavily on computer technology, signal processing, and electromechanical design.

This cooperative arrangement has proven very beneficial in highly automated projects, such as in the recently developed award-winning CIGAR. Pushed by remote control down the fuel channel by a large, external, electromechanical machine, the apparatus goes to the core of CANDU's nuclear reactors to find cracks, to measure the diameter and thickness of pressure tubes, and to detect changes brought about by heat and radiation. To achieve this end, computers, electromechanical components, lasers and laser beam image recorders, optics and optical tooling, and machine tool control systems were utilized.

Eddy current technology was also utilized in pressure tube work. The focus was on the development of deconvolu-



Shown here is a profilometry module, a device designed to monitor wear in pressure tubes by producing profiles of wear/erosion and debris damage in fuel channels. The device, developed by the Nondestructive Evaluation Unit, is used in conjunction with the CIGAR system.

tion techniques to improve the quality of information provided by inspection systems. Additional interest centred on the design and prototyping of a resistivity measuring system that will be used to determine hydrogen concentrations in pressure tubes.

Ultrasonic technology is being utilized to detect, characterize, locate, and size flaws in pressure tubes through processes such as crack-tip diffraction and "B-scans". Additionally, very high-frequency ultrasonics have been applied successfully to imaging lap-like defects. It was such a defect that caused the failure of a pressure tube at Bruce NGS. Ultrasonic techniques may also be useful in a process cur-

rently being investigated to measure hydride platelet concentrations in pressure tubes.

Although the Department has a heavy commitment to the fuel channel research program, other components of nuclear generating plant must receive attention. In pressurized water reactors, steam generator tubing is susceptible to stress corrosion cracking, localized corrosion under sludge deposits, and corrosion fatigue. To predict the susceptibility of the CANDU system to these mechanisms, exposure testing using laboratory simulations is being carried out. The result will be the establishment of a data base applicable to CANDU operating variables. Temperature, alloy heat treatment, and water chemistry are considered key factors in these corrosion mechanisms.

To study localized corrosion initiation and propagation effects in Lake Ontario water, heat exchanger test rigs continue to operate at the Pickering and Darlington nuclear stations. Testing to date suggests the probable central role played by microbiological action. The rigs facilitate the realistic testing of remedial measures such as chemical cleaning and biociding. A technique of measuring the corrosion rate electrochemically is being developed.

Effort on the Darlington Heat Transport System Leak-Before-Break study focused largely on providing analytical support to the Design and Development Division regarding the three-dimensional elastic-plastic fracture mechanic analysis of elbows and T-junctions and on producing documents for the Darlington licensing submissions.

The Department's work done in support of thermal plant was concentrated in the life extension program. Sections of large components taken from Lakeview TGS were sent to the Research Division for examination. These samples will provide a rare opportunity to investigate the age-related degradation of carbon steel pipes, components, and welds that have been in service for almost 20 years. Testing of the samples will begin in 1989, the purpose being to evaluate the suitability of these materials for plant use well beyond their initial design life of 30 years. The largest single project being carried out in support of thermal plant is the metallurgical "fingerprinting program", which is part of the Lambton life assessment program. Because this is described in the earlier article on the Division's contributions to Corporate Strategy, it requires little mention here except to note that the in situ metallurgical evaluation capability is subject to continual development and that the capability is frequently called upon.

Other work related to thermal plant metallurgy included an EPRI-funded corrosion-fatigue study. The study involves the development of a technique to simulate the types of failure observed in operating plant. To aid this research, a loop facility with controlled water chemistry was developed. In addition, the facility has a loading system able to produce cracks on the inside surface of a tube specimen. The results of tests performed in this facility will be used to identify those operating parameters having the largest influence on the corrosion-fatigue failure of boiler tubes in thermal plants.

In 1988, the Department's failure analysis service was concerned with a wide variety of system materials and components. Of particular concern were several instances of fatigue cracking of the high-integrity piping at Darlington and Bruce "B" and corrosion attack on steam generator tubing at Pickering GS. The problem at Pickering later turned out to be much less severe than was anticipated.

The Welding Unit of the Metallurgical Research Department performs research and development in welding and joining. The Unit is also responsible for the qualification of new and revised standard welding procedures for Corporation use. A major R & D emphasis for many years has been on a CEA, Institut Recherche Electricité de Québec (IREQ), and Research Division effort to develop automated and remote welding methods. An important achievement of this collaborative project has been the creation of a compact robotic system for in situ repair of cavitation damage to hydraulic turbine runners. In 1988, work on this system included refinement of the advanced "self-programming" control concepts and the welding procedures used by the system. In addition, the prototype equipment was rebuilt and tested in the field.

Research on welding automation has also advanced in the area of circumferential joints, such as are needed in piping and spent fuel container closures. Special efforts were made last year to improve welding productivity in pipe welding and to optimize processes such as pulsed-gas metal arc and flux-cored arc welding. Technology transfer is always a priority, and to this end, training of field staff in advanced methods was ongoing throughout the year. Excellent results have been reported from field implementation of these methods. A longer-term objective is to define ways in which automated systems can cope with unforeseen variability in joint fitup or presentation. To address this need, experimental work on the use of machine vision is underway.

Tritium technology is another active concern of the Department. A new tritium laboratory research and testing facility, equipped with glovebox work stations, protective alarms, and monitors, is almost fully functional at this time. Associated decontamination facilities, clean-up systems, and a tritium supply and delivery system are about to be completed. The safe management and use of an inventory of three kilocuries of tritium can now be demonstrated. Technical support is being provided to the Darlington Tritium Removal Facility, and this includes commissioning and operating assistance, examining the adverse effects of tritium on vacuum pump oils, decontamination of metal components, and exposure testing of a variety of diagnostic devices. Consultation services have been made available to the University of Toronto, the Canadian Fusion Fuels Technology Program, and Hydro's own Tritium Application Program.

A hydrogen pump, which relies on the permeation of atomic hydrogen through bilayer metal membranes, has been developed. There are a number of potential commercial applications of this concept that concern tritium handling and the making of diagnostic measurements in fusion reactor devices. Testing of these is ongoing in the TEXTOR tokamak. Research has also resulted in the development of safe and efficient methods for managing tritium by immobilizing it on high-performance uranium and zirconium-iron getter beds. Some of these beds have already been commercialized. Further work has developed practical systems so that these getters can be used for on-line scavenging of tritium from gas process streams with detritiation factors as high as 10^4. New alloys such as zirconium-cobalt are also being tested and have the potential to replace uranium for temporary tritium storage.

Finally, a description of two new initiatives introduced

Eighteen-channel multiplexer, which is to be used in underwater service, is being encapsulated in radiation-resistant epoxy. This device will enable many more probes and sensors to be used on the inspection heads of pressure tube inspection systems.

Technician Tom Ryans is involved in the surface preparation required for in situ metallography.

this year to the Metallurgical Research Department: First, the Advanced Industrial Materials Project will be responsible for research into metallic materials required for the continued reliable supply of electricity into the twenty-first century. Work will be concentrated on materials such as composite alloys for fashioning transmission hardware, superconductive materials, and advanced alloys for high-temperature applications in generating plant. Second, a new activity to be developed in support of demand management will examine ways of increasing the efficiency of the metallurgical and materials processing industry. Metals producers are some of Ontario Hydro's most important customers.

The Metallurgical Department considers itself to be carrying out a successful research and development function. This success is due, in part, to the creativity and innovation that is evident in every undertaking — qualities inherent to the discipline of Metallurgy itself. In this Department, risk taking is encouraged: to try something that does not work is not a failure, whereas not to try it is.

OPERATIONS RESEARCH:

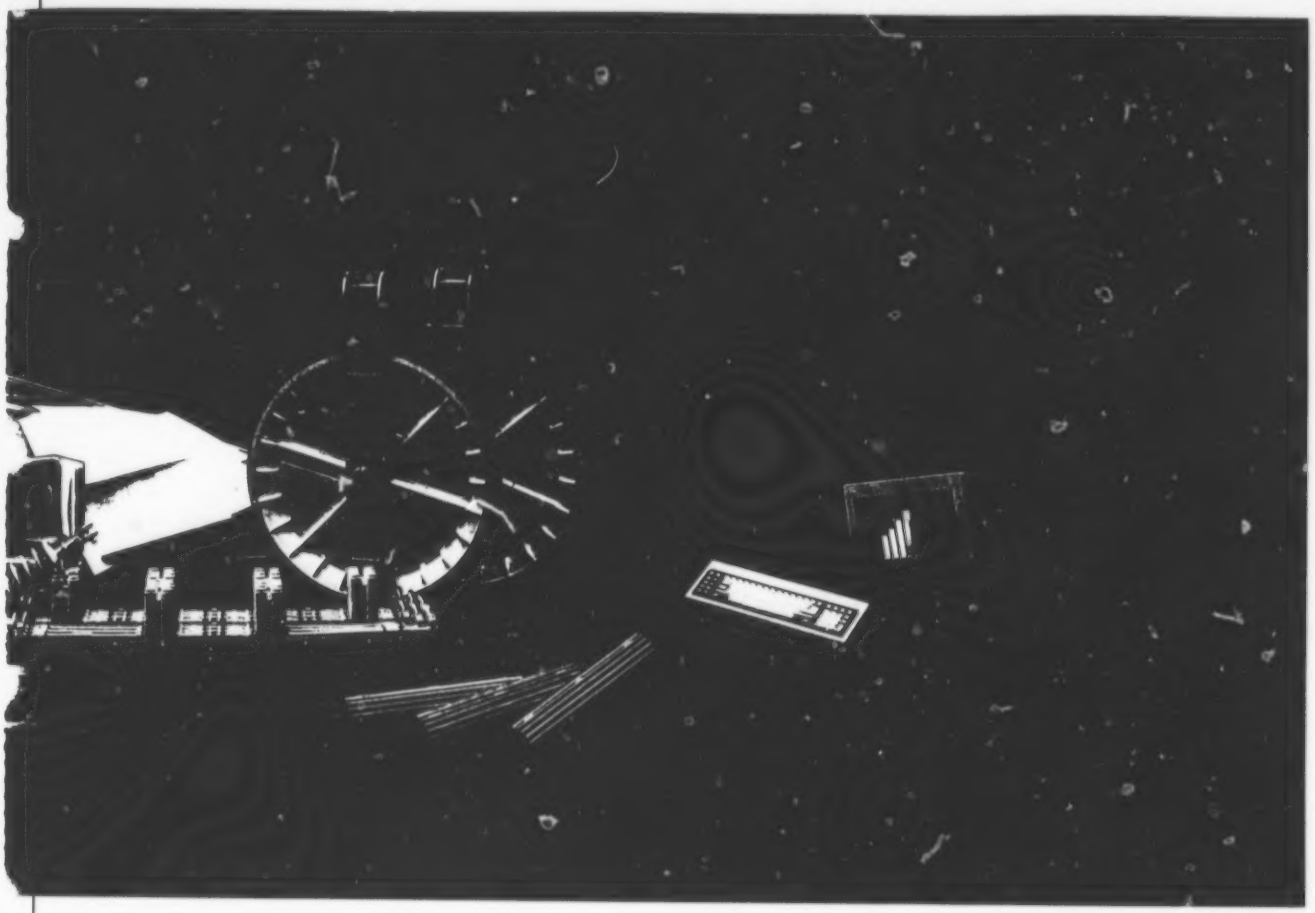
Over the years, the Operations Research (OR) Department has assembled a team of highly trained specialists drawn from a variety of disciplines. These specialists carry out a wide range of studies for management, technical departments, and individual researchers. In these studies, scientific methods are applied to complex operational and strategic problems usually related to the management of systems and procedures; men and equipment; materials and money; and data and information. Handling the complexities of these often unusual studies requires the use of a full range of state-of-the-art mathematical methodologies and up-to-date computer facilities.

In 1988, the client base and the range of services offered by the Department continued to expand in areas of decision and operational analysis, statistical analysis, and power system reliability modelling. Services are varied, ranging from informal consultations and short presentations, through large-scale projects, to tailor-made courses and seminars. Additionally, specialized computer application services are made available to the staff of the Research Division.

Operations Research is a label coined in World War II to describe the scientific analysis of military operations. Since then the term has been adopted in business, industry, and government. Increasingly, scientific methods have been used to enhance management effectiveness and operational efficiency. Traditional techniques such as linear programming, inventory control, and queuing theory were always important to management studies, and they are becoming more so as essential components in the development of decision support systems. Researchers then must be sensitive to the decision environment and must develop innovative new approaches where appropriate. Growing interest in the measurement of intangibles and in complex decision processes provides an additional challenge. Problems often involve several, frequently conflicting, objectives, the ideal solution not always being readily apparent.

In 1988, the decision and operational analysis team achieved a high degree of diversification in areas of consulting and research. Services were provided to several Divisions, including Technical, Training and Services, Comptroller's, Market Services and Development, Power System Operations, Supply, Real Estate and Security, Transmission Operations, System Planning, Design Development — Generation, Economics and Forecasts, and Thermal and Hydraulic Generation. Some examples of the consulting and research projects are multi-criteria decision analysis for use in finance, system planning, and marketing programs; the application of the integer programming technique to the selection of bids; the development of expert systems to automate procedures as diverse as selecting channels for nuclear fueling studies and assisting in library literature searches; the development of an integrated approach to transmission and generation outage planning; modelling of energy production costs; and the optimization of office planning, design, furniture inventory, and scheduling of physical moves.

Since a reliable supply of electrical energy is part of



Hydro's mandate, accurate reliability predictions for power systems and their constituent parts is a most important engineering task. Equally critical is the assessment of risk involved in many operating situations. In some aspects, the development of reliability methodology based on probabilistic modelling has come a long way in the last 25 years, but it is still not mature enough for use in all applications. The Department's reliability team, however, is at the forefront of the world-wide effort to develop more advanced reliability tools.

The team's involvement with the development and application of mathematical models for system and component reliability spans almost two decades. The aim of this work has been to assist Hydro's planning, operating, design, and maintenance functions. In 1988, the reliability team continued to engage in developmental work and in the provision of consulting assistance to other Divisions. Important progress has been made in optimization of maintenance procedures, and new concepts and modelling techniques were introduced to represent the processes of deterioration and failure. This year most of the work on the reliability evaluation of the control and operating facilities for the new System Control Centre at Clarkson was completed.

Through their publications and participation on committees and in conferences, the staff of the reliability team have earned an international reputation. This year, staff participated in a number of international technical activities, which included participation in the presentation of a new Power System Reliability Analysis Application Guide at the 1988 International Conference on Large Electrical Systems (CIGRE) meeting, continuation of industry advisory activities for several EPRI research projects, and the presentation of a week-long seminar on power system reliability analysis at the Xi'an Jiaotong University in China. The seminar was conducted under CIDA sponsorship.

The selection and analysis of data for technical or management studies often appear straightforward and may indeed be so in a simple case. However, when data are scarce, interrelated, dispersed, or even contradictory, the drawing of valid conclusions requires skill and training in advanced statistical analysis. The statistics team was formed several years ago when Corporation-wide need for expert assistance in data collection and evaluation was perceived. Assistance in solving statistical and mathematical problems is provided by the statistics team, whose expertise includes knowledge of sampling schemes, statistical estimation, design of experiments, forecasting, regression analysis, probability theory, mathematical modelling of engineering systems, quality control, and quality assurance.

In 1988, the team performed a number of diverse studies for other Divisions as well as for the Research Division. Studies included the identification of relationships among performance and cost indicators for nuclear and hydraulic sources of energy production; the statistical design of reproducibility experiments for petroleum standards tests; statistical analysis of bursting characteristics of rupture pressure

Current work in the Operations Research Section includes the development of microcomputer-based water allocation models to maximize the output of Hydro's hydraulic generating stations. Station engineers use these computational techniques interactively when making decisions about station operations.

relief panels scheduled to be installed at the Pickering NGS; and a proposal for a sampling scheme to estimate the energy saving of retrofitted electrically heated homes. In addition, members of the team participated in the working party on the Environmental and Safety Research Assessment of the CANDU Owner's Group Waste Management Program. Assisting clients through informal consultations continues to be an important part of the team's activities.

Rapid advancement in computer technology provides the staff of the computer support team with a great challenge, and in 1988, the team continued to provide specialized programming and consulting services to the staff of the Research Division. The team also increased its efforts in the research, evaluation, and introduction of new computer technologies. Macintosh facilities with large screens, optical scanners, and high-quality laser printers were purchased and installed for productivity enhancement in report and presentation preparations. Many second generation, integrated PC software packages were evaluated and introduced to staff in the Research Division.

The advancement in computer and information technology has also created a number of opportunities of strategic importance to the effective and efficient operations of Ontario Hydro. Among them are artificial intelligence and database technology. In 1988, the Department was engaged in the successful development of prototype expert systems. Identification of high payback opportunities continued. The development of uncertainty treatment in machine vision continued as part of our participation in the PRECARN project. Exploratory work for active research in neural networks has begun. Possible applications of this technology to fish identification seem promising. With rapid developments in these new fields, special applications in robotics, pattern recognition, and knowledge preservation and distribution are anticipated in the very near future.

In 1988, the Department was involved in external activities with universities, professional associations, and research institutes. A number of staff members held Adjunct Professorships or served as executives or committee members with professional societies or research granting agencies. Informal collaborative research arrangements were made with universities. Internships were offered to the University of Strathclyde and Glasgow. Staff were also invited to make technical presentations at various universities and industries.

Under contract with Polysar Ltd., Dr. Hormoz Azizian (Chemical Research) developed new rubber technology at the University of Waterloo. The technology received the 1987 Gold Award of Excellence in the invention category at the Canada Awards for Business Excellence. Already, the new highly saturated nitrile rubber has been earmarked for uses that include high-pressure seals, oil well blowout preventers, gaskets, diaphragms, hoses, tubing, flexible fuel cells, conveyor belting for hot or corrosive materials such as asphalt, and hydraulic system seals and liners.

Carrying on the tradition of excellence started by R. B. Young, a paper co-authored by Tom Carmichael, Douglas Hooton, P. K. Mukherjee, and Val Sturrup (all of Civil Research) was awarded the Wason Medal for Materials Research by the ACI. The paper, entitled "Evaluation and Prediction of Concrete Durability: Ontario Hydro's Experience", was selected from among the many papers presented in ACI journals or at conference proceedings during 1987.

Ontario Hydro's New Business Ventures Division selected Dr. H. S. Radhakrishna (Civil Research) as one of its 1988 Product Champions. In the award category of Project Management, Dr. Radhakrishna was recognized for the leadership and coordinating role he played in the successful delivery of Ontario Hydro's Long Island Sound cable crossing project.

Bob Koopmans and Robin Hughes (Civil Research) received a Research Division Director's Award for the development of shallow and deep borehole dilatometers and for the invention of a hydraulic rock breaker tool. The dilatometers are now standard instruments for assessing rock conditions for facilities constructed of rock formations, such as intake or cooling tunnels and nuclear waste repositories. The breaker tool is used by Ontario Hydro in situations in which conventional drilling and blasting cannot be used.

Visitors to the Division now receive a 'Pocket Facts' card that doubles as a name tag. In the Society for Technical Communication (STC) 1988 Competition, two members of the Research Publications Office, Barbara Brown and Lisa Bell (Divisional Services), received an award of excellence for the technical writing and design of this novel promotional material. The STC is the world's largest professional organization devoted to the arts and sciences of technical communication.

The Research Division Annual Report for 1987 won two awards in the 1988 STC Competition. Gary Floyd, Keith Buck, Lisa Bell, and Barbara Brown (all of Divisional Services), Dave Young (Divisional Projects), and Spencer Bush (Information Services Division) earned achievement awards, one for art and design and the other for technical writing.

Greg Stone (Electrical Research), an active participant in the technical and administrative activities of the Institute of Electrical and Electronic Engineers (IEEE), was elected President of the IEEE Dielectrics and Electrical Insulation Society (DEIS) for the 1988-1989 term. DEIS publishes the *Electrical Insulation Magazine*, which has 15 000 subscribers, and a scholarly journal, the *IEEE Transactions on Electrical Insulation*. The society hosts several conferences each year and is responsible for creating American National Standards.

Dr. Jim O'Neill (Electrical Research) received a U.S. patent for his development of a Waveguide Reaction Cell. The invention is useful for laser isotope separation work.

Wilf Watson, retired Section Head of System Studies Section, Dave Lee, Roger Beaulieu, and Gerry Manchur (all of Electrical Research) received the 1988 W. P. Dobson Award for outstanding technical innovations of benefit to the Corporation and the electric power industry. Developed and implemented were novel excitation control schemes and better models for the enhancement of power system stability. These power system stabilizers have been supplied by Ontario Hydro to locales as wide ranging as Saskatchewan, New Brunswick, and Australia.

The H. A. Smith Award, awarded annually by the Research Division for outstanding contributions that have had a major impact on R & D business, went this year to Dr. Tom Byrne (Mechanical Research) and Dr. Marc Leger (Metallurgical Research) for their research on hydride blister formation in pressure tubes. They undertook a comprehensive research program to determine the consequences of pressure tube / calandria tube contact for Zr-2.5 wt% Nb pressure tubes.

An interdisciplinary team effort of Design & Development Division and the Mechanical and Chemical Research Departments resulted in the invention, development, and demonstration of the 'fish hammer', an acoustical device for controlling fish movement in the vicinity of structures such as generating station cooling water intakes. The combined effort of Dr. Al Christie (Design & Development), Jerry Forest and John Kowalewski (Mechanical Research), and Dr. Paul Patrick (Chemical Research) was rewarded by a U.S. patent and a Research Division Director's Award. The technology is being transferred to a commercial setting.

Dr. Mike Dolbey (Metallurgical Research) was awarded the prestigious Engineering Medal of the Association of Professional Engineers of Ontario (APEO) in 1988. The Engineering Medal recognizes achievements significantly above the normally high standards of the profession. Dr. Dolbey headed a group of engineers and researchers in a project to create special technology to inspect tubes within a CANDU reactor.

The Fracture Mechanics Unit of the Nondestructive and Fracture Evaluation Section was recognized for its analytical and experimental work in elastic-plastic fracture mechanics with a Research Division Director's Award. The research of Dr. Mukul Mukherjee, Bert Vanderglas, Doug Scarth, Olev Lepik, and Dave Carpenter (Metallurgical Research) led to the acceptance of the leak-before-break rationale.

The ICE team, consisting of Dr. Archie Chung, Manager of Operations Research, Dr. Jim Tulk (Mechanical Research), and Alda McMahon (Divisional Services), merited a 1988 Director's Award for its outstanding effort in coordinating inputs, identifying needs, and providing strategies, recommendations, and plans for the development of an integrated computing environment for the Division.

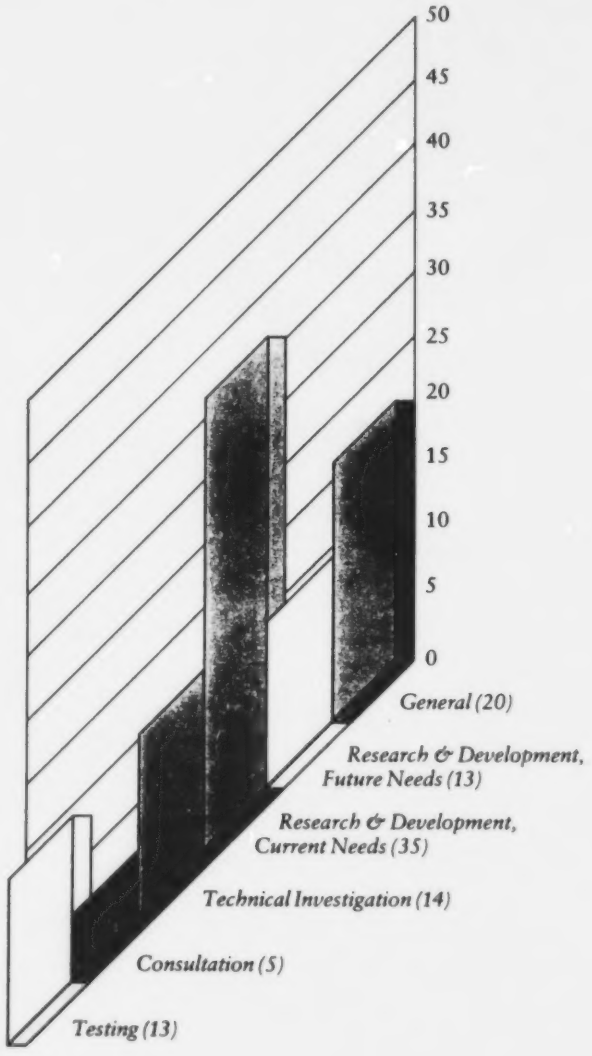
RESOURCES AND COSTS

At the end of 1988, the Division's personnel resources consisted of a total regular staff of 640. The percentages of funds allocated to major work programs and the percentages of program costs attributable to OM&A — the net cost to Ontario Hydro to operate, maintain, and administer the Research Division — are shown below. Also shown are proportions of Research Division costs for various categories of work and distribution of staff in broad occupational classes.

The total of all costs, including those for space, materials, and equipment, for work done by the Research Division in 1988 was approximately $68.3 million.

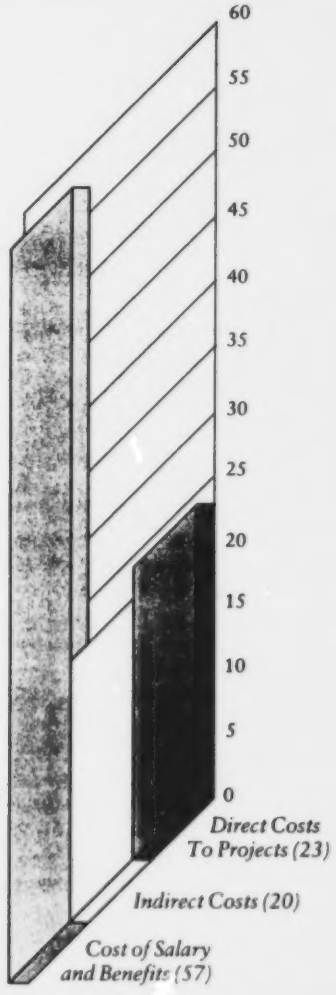
Costs were met or allocated as follows:

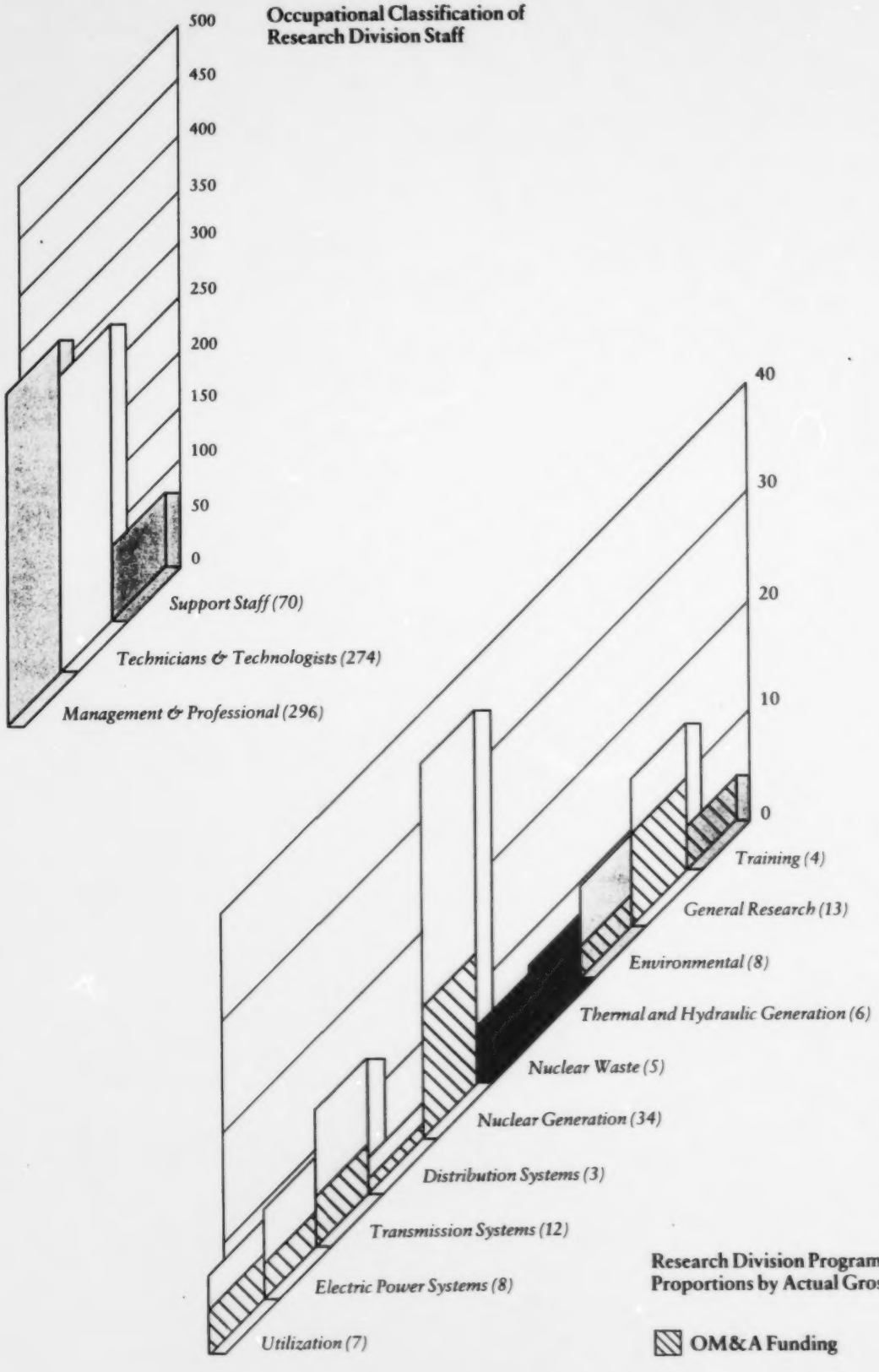
Revenue from Work Done for Other Organizations	4.7
Transfers to Other Ontario Hydro Branches	35.0
Transfers to the Cost of Power	28.6



Proportions of Research Division Costs for Various Categories of Work

Research Cost Breakdown by Major Resource Categories (% of Gross Costs)




Occupational Classification of
Research Division Staff
500
450
400
350
300
250
200
150
100
50
0
Support Staff (70)
Technicians & Technologists (274)
Management & Professional (296)
40
30
20
10
0
Training (4)
General Research (13)
Environmental (8)
Thermal and Hydraulic Generation (6)
Nuclear Waste (5)
Nuclear Generation (34)
Distribution Systems (3)
Transmission Systems (12)
Electric Power Systems (8)
Utilization (7)
Research Division Programs for 1988-
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ACRONYMS

ACI	American Concrete Institute
AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
AI	Artificial Intelligence
AMTU	Advanced Materials Technical Unit (at Queen's University)
APEO	Association of Professional Engineers of Ontario
ASIC	Application Specific Integrated Circuit
ASTM	American Society for Testing and Materials
BEEF	Biological Effects of Electro-Magnetic Fields
BLIP	Blister Location Inspection Package
CANDU	Canada Deuterium Uranium (reactors)
CDEPTH	Creep Degradation Evaluation in Pressure Tubes (Hydro)
CEA	Canada Electrical Association
CIDA	Canadian International Development Agency
CIGAR	Channel Inspection and Gauging Apparatus for Reactors
CIGRE	Conference on Large Electrical Systems
CIRAC	Canadian Institute for Research in Atmospheric Chemistry
CNS	Central Nuclear Services
COG	CANDU Owner's Group
CPSD	Central Production Services Division
CSA	Canadian Standards Association
CUICAC	Canadian University and Industry Council on Advanced Ceramics
DEIS	Dielectrics and Electrical Insulation Society
EPCRI	Electric Power Construction Research Institute (China)
EPRI	Electric Power Research Institute
FGD	Flue Gas Desulphurization
GEMS	Generator Expert Monitoring System
IBSS	Iron Based Stressed Shell
ICE	Integrated Computing Environment
ICP	Inductively Coupled Plasma
IEEE	Institute of Electrical and Electronics Engineers
IREQ	Institut Recherche Electricité de Québec
MFRRS	Magnetic Field Rodent Reproductive Study
NDFE	Nondestructive Fracture Evaluation
NGS	Nuclear Generating Station
NO_x	Nitrogen Oxides
NPD	Nuclear Project Demonstration
NPLA	Nuclear Plant Life Assurance
OCMR	Ontario Centre for Materials Research
OR	Operations Research
PHT	Primary Heat Transport
PIPE	Packaged Inspection Probe
PRECARN	Precompetitive Applied Research Network
SLAR	Spacer Location and Repositioning
SWIPE	Steam-Water Iodine-Partitioning Experiment
TAP	Technical Assistance Program (Ontario Hydro)
TGS	Thermal Generating Station
TWPP	Thin Walled Particulate Packed (container)
URL	Underground Research Laboratory
WNRE	Whiteshell Nuclear Research Establishment

From left to right: G. (Gerry) Manchur, D.C. (Dave) Lee, and R.E. (Roger) Beaulieu, all of the Electrical Research Department.

SIGNIFICANT RESEARCH CONTRIBUTION

Ontario Hydro's power system is operating smoothly. To be able to say this of a system limited by its transmission capabilities is to pay sincere tribute to a protracted and intensive research and development effort carried out at Ontario Hydro. Key players are the Research and System Planning Divisions, which, as long ago as the early 1960s, initiated an intensive effort to develop and implement novel excitation control schemes and better models for the enhancement of power system stability.

Since this early effort, work related to power system stability control has come a long way. Each application of a power system stabilizer has resulted in the development of a refined version. By the early 1960s, the first speed-based delta-omega stabilizers were developed for application in hydraulic units. Later application of this design in a fossil-fired station presented problems that further research attributed to torsional oscillations. These problems were resolved, and since then a more efficient stabilizer (the delta-P-omega stabilizer) has been developed.

To maintain stability following severe system faults, a transient stability excitation control was developed and installed on major generating units. These innovative designs would not have been possible without the concomitant development of analytical models, such as new mathematical models for generators and their controls. This combination of stability controls has allowed increased power transfer without risk of system instability, thereby saving Hydro's customers millions of dollars.

The significance of this highly innovative research contribution is probably best appreciated only by power system experts. However, the success of the cooperative effort of Research and System Planning Divisions is attested to by its world-wide recognition. Power system stabilizers have been supplied to Saskatchewan, Nova Scotia, New Brunswick, and Australia with consulting services being provided in places as far flung as China and Taiwan. The Hydro approach to power system stabilization is a de facto industry standard, establishing Ontario Hydro as the undisputed leader in power system stability analysis and control.